ANSV AGENZIA NAZIONALE PER LA SICUREZZA DEL VOLO

FINAL REPORT

ACCIDENT
occurred to the
AgustaWestland AW609 aircraft registration marks N609AG,
in Tronzano Vercellese (VC),
on the 30th of October, 2015

OBJECTIVE OF THE SAFETY INVESTIGATION

The Agenzia nazionale per la sicurezza del volo (ANSV), instituted with legislative decree No 66 of 25 February 1999, is the Italian Civil Aviation Safety Investigation Authority (art. 4 of EU Regulation No 996/2010 of the European Parliament and of the Council of 20 October 2010). **It conducts, in an independent manner, safety investigations.**

Every accident or serious incident involving a civil aviation aircraft shall be subject of a safety investigation, by the combined limits foreseen by EU Regulation No 996/2010, paragraph 1 and paragraph 4 of art. 5.

The safety investigation is a process conducted by a safety investigation authority for the purpose of accident and incident prevention, which includes the gathering and analysis of information, the drawing of conclusions, including the determination of cause(s) and/or contributing factors and, when appropriate, the making of safety recommendations.

The only objective of a safety investigation is the prevention of future accidents and incidents, without apportioning blame or liability (art. 1, paragraph 1, EU Regulation No 996/2010). Consequently, it is conducted in a separate and independent manner from investigations (such as those of Judicial Authority) finalized to apportion blame or liability.

Safety investigations are conducted in conformity with Annex 13 of the Convention on International Civil Aviation, also known as Chicago Convention (signed on 7 December 1944, approved and made executive in Italy with legislative decree No 616 of 6 March 1948, ratified with law No 561 of 17 April 1956) and with EU Regulation No 996/2010.

Every safety investigation is concluded by a report written in a form appropriate to the type and seriousness of the accident or serious incident. The report shall contain, where appropriate, safety recommendations, which consist in a proposal made with the intention of preventing accident and incidents.

A safety recommendation shall in no case create a presumption of blame or liability for an accident, serious incident or incident (art. 17, paragraph 3, EU Regulation No 996/2010).

The report shall protect the anonymity of any individual involved in the accident or serious incident (art. 16, paragraph 2, EU Regulation No 996/2010).

GLOSSARY

AGL: Above Ground Level.
AMSL: Above Mean Sea Level.
ANSV: Italian Civil Aviation Safety Investigation Authority.
AOA: Angle of Attack.
AOB: Angle of bank, see BANK.
APC: Aircraft Pilot Coupling, rare, unexpected and unintended excursions in aircraft attitude and flight path caused by anomalous interactions between the aircraft and pilot.
BANK: (AOB, Angle of Bank) aircraft inclination in degree along its longitudinal axis.
BRIEFING: preventive description of manoeuvres or procedures.
CAS: Caution and Advisory System.
CAS: Computed Air Speed.
CFD: Computational Fluid Dynamic.
COCKPIT: Flight Deck Compartment.
CVR: Cockpit Voice Recorder, records communications, voices and noises inside the flight deck.
DCP: Differential Collective Pitch, FCC control law responsible for stabilization and control of the yaw axis behaviour of the aircraft in response to pedal inputs, lateral accelerations and yaw rate sensors.
DIVE: steep descent manoeuvre in flight at high speed.
EASA: European Aviation Safety Agency.
ENAC: Italian Civil aviation Authority.
EPDU: Engineering Pilot Display Unit, screen in the *cockpit* representing the values of the parameters relative to flight tests.
FAA: Federal Aviation Administration, American Civil Aviation Authority.
FCC: Flight Control Computer.
FCS: Flight Control System.
FDR: Flight Data Recorder.
FFC: Fixed Flight Controls.
FH: Flight Hours.
FLAPPING: blade movement of the proprotor that, by pivoting around the coupling, amplifies movement more on the extremities.
FSTD: Flight Simulation Training Device.
FTI: Flight Test Instrumentation.
G: gravitational acceleration.
GS: Ground Speed.
HDG: Heading.
IAS: Indicated Air Speed.
ICAO/OACI: International Civil Aviation Organization.
ICDS: Interconnecting Drive Shaft.
ICS: Intercommunication System.
IDLE: engine thrust lever position corresponding to minimum thrust.
KIAS: IAS in knots (kt).
KT: knot, unit of measure, a nautical mile (1852 metres) per hour.
MCC: Multi Crew Coordination.
METAR: Aviation routine weather report.
MN: Mach Number, relationship between the speed of an object in movement in a fluid and the speed of sound in the fluid itself.
MPFR: Multi Purpose Flight Recorder, combined flight recorder CVR/FDR.
MRT: Multi Radar Tracking.
MTOM: Maximum Take Off Mass.

NACELLE: casing of an aerodynamic shape made to contain the engine and proprotor system of the aircraft.
NM: nautical miles (1 nm = 1852 metres).
NTSB: National Transportation Safety Board.
OML: Valid only as or with qualified co-pilot.
PDU: Pilot Display Unit.
PF: Pilot Flying.
PIC: Pilot in Command.
PITCH: rotation on the lateral axis of an aircraft.
PNF: Pilot Not Flying.
PRGB: Propeller Gearbox.
PROPROTOR: rotating airfoil used as a propulsion device both in airplane mode (propeller) and helicopter (rotor) during the same flight.
QBAL: Torque Balancing, which is the integral term within the algorithm of the FCS control logic responsible fro the compensation of the asymmetries influencing the directional control.
QBALTH: Torque Balancing Ratio, which is the real time ratio between th QBAL value and the FCS total Pedal authority, and is displayed in the cockpit on the EPDU.
ROLL: rotation on the longitudinal axis of an aircraft.
SHP: Shaft Horse Power.
SIDESLIP: aerodynamic state in which an aircraft rotates around its vertical axis while at the same time moving in the direction of motion.
SIMRX: engineering flight simulator developed for the aircraft AW609.
S/N: Serial Number.
SPATIAL-D: Spatial Disorientation, temporary or permanent disturbance characterized by mental confusion, difficulty in remembering recent or past events, and in movement coordination.
T/B/T: radio communications ground-aircraft-ground.
TML: Valid only for … months, limitation of the medical certificate, applied when the validity is limited in time, for reasons described by the authorized aeromedical examiner.
UTC: Universal Time Coordinated.
YAW: rotation of the aircraft on the vertical axis.
VMO: Velocity Maximum Operating.
VNL: limitation of the medical certificate by which the holder has to dispose of corrective lenses for near sightedness and has to hold with him a reserve pair of eyeglasses.

This report has been translated and published by the ANSV for the English-speaking concerned public. The intent was not to produce a factual translation and as accurate as the translation may be, **the original text in Italian is the work of reference**.

Questa relazione d'inchiesta è stata tradotta e resa disponibile in lingua inglese a cura dell'ANSV a beneficio delle persone interessate. Benché grande attenzione sia stata usata allo scopo di offrire una traduzione accurata, **il testo di riferimento rimane quello in lingua italiana**.

ACCIDENT
Aircraft AW609 registration marks N609AG

Type of aircraft and registration	Tiltrotor (experimental) AgustaWestland AW609 registration marks N609AG (photo 1, attachment “A”).
Date and time	30th of October 2015, around 09.42’ UTC (10.42’local time).
Place of the event	Tronzano Vercellese (VC), location coordinates: N 45° 21.24 E 008° 09.22 (figure 1).
Event Description	The aircraft took off from Cascina Costa (VA), location of production and headquarters of the manufacturer, for a programmed and planned test flight, that foresaw the transfer to a reserved airspace near the city of Santhià (VC). While performing a high-speed descent (the third from the start of the test flight T664), the aircraft entered initially an uncontrolled flying condition, due to a series of lateral-directional oscillations, then suffered structural breakup followed by in-flight fire and impacted the ground. Both test pilots on board suffered fatal injuries.
Aircraft Operator	AgustaWestland Philadelphia Corporation.
Nature of the flight	Test flight of an experimental aircraft.
Persons on board	Crew: 2.
Damage to aircraft	Destroyed.
Other damage	No damage to third parties on the ground resulted.
Personnel information	***Captain.*** Male, age 53, American (US) nationality. He had more than 20 years of flying experience on 35 different aircraft types (aeroplanes and helicopters) and obtained the qualification as experimental test pilot in 1997 at the Naval Test Pilot School of Patuxent River (USA). He had then been hired as test pilot by Bell Helicopter and assigned to the Tiltrotor (BB609) project, until it was acquired by AgustaWestland, where he had been employed in 2011 (in the meantime the project had been renamed AW609). At the time of the accident he did not cover any other specific hierarchical position within the Company’s organization. He held 2 pilot licenses, issued respectively, by the competent Civil Aviation Authorities of the United States (FAA) and Italy (ENAC). Both licenses were valid at the time of the event; in particular, he held an American ATP, Airline Pilot Licence with current ratings on helicopters AB139 and AW139. He was also

authorized to exercise the provisions foreseen by a commercial pilot licence on single and multi engine aircraft. He had a current IR rating.
The FAA, via a letter of temporary authorization dated 12th of November 2014 and valid until the 30th of November 2015, authorized him to exercise the role of PIC on experimental aircraft AgustaWestland AW609 registration marks N609AG (prototype 2). The licence issued by ENAC comprised the title of production test pilot (Cat 1).
The first class medical certificate was valid, with VNL limitation.
Before being employed in AgustaWestland, he had a total flight experience of 4100 flight hours, of which 1300 as test pilot. Between 2010 and 2015 (for one year in Bell Helicopter and from 2011 in AgustaWestland) he had performed 357h 40’ of flying activity on both tiltrotor prototypes AW609. Part of the test flight activity on the tiltrotor had been done on prototype 1 (as co-pilot) and in part on prototype 2. In particular, from January 2010 until the 30 th of June 2014 he had performed test flight activity on prototype 2. In July 2014 he had performed 12h 20’ of flying activity on prototype number 1 (S/N 60001) in the United States. Some months after a temporary stop of the prototype 2, due to the proprotor strike event that occurred on the 17th of July 2014, he had started again test flight activity on prototype 2 in January 2015. In the month of July 2015 he had flown once more on prototype 1 for 04h 25’ and after that in August 2015 at the date of the accident on prototype 2. In the 90 days preceding the accident he had flown around 99 hours total, of which 13h 45’on aircraft AW609 registration marks N609AG.

Copilot.
Male, age 52, Italian nationality.
He had more than thirty years of flying experience on more than 50 different aircraft types (both aeroplanes and helicopters). He was a pilot in the Italian Air Force for more than 16 years, and he obtained the experimental test pilot qualification in 1993 at the Naval Test Pilot School of Patuxent River (USA) and had been employed, after a long experience in the Air Force, as experimental test pilot in AgustaWestland in 1999.
At the time of the accident he also covered the role of “AW609 Development Lead Pilot” in AgustaWestland.
He held 2 pilot licenses, issued respectively, by the competent civil aviation authorities of the United States (FAA) and Italy (ENAC). Both licenses were valid at the time of the event; in particular, he held an American ATP, Airline Pilot Licence with current ratings on single and multi engine aircraft and on helicopters AB139, AW139, AW169.
The FAA, via a letter of temporary authorization dated 22nd of June 2015 and valid until the 1st of June 2016, to exercise the role of PIC on experimental aircraft AgustaWestland AW609

registration marks N609TR (prototype 1) and N609AG (prototype 2).
As previously mentioned he also held an airline helicopter pilot licence issued by the Italian Aviation Authority (ENAC), in accordance with Part-FCL, and he held the following valid type ratings: A139, A139 (IR), A109, A109 (IR), AW189 (IR), experimental test pilot (Cat 1).
The first class medical certificate was valid, with VNL, TML and OML limitations.
Before 2010 he had a total flight experience of 7400 flight hours, of which 5000 as experimental test pilot. Between 2010 and 2015 (at AgustaWestland) he had flown 5563h 05'flight hours on prototypes, of which 315h 35' on tiltrotor prototype AW609. The test flight activity on the tiltrotor had been done partly on prototype 1 and 2. In particular, 129h 45' hours of flight had been performed on prototype 1 and e 185h 50' on prototype 2.
After some months of temporary stop of the prototype 2 due to the proprotor strike event that occurred on the 17th of July 2014, he had started flight test activity again on prototype 2 in January 2015.
In the 90 days before the accident he had flown a total of 77 hours of which 15h 55' on aircraft AW609 registration marks N609AG.

Aircraft and engine information

The AW609 is an experimental tiltrotor aircraft, able to convert in flight from helicopter to aeroplane by rotating the two proprotors, installed on the nacelles on the wingtips, from the vertical position (90 degrees) to the horizontal position (0 degrees) and viceversa.
The MTOM used only in the experimental phase is 8.165 kg, with a MTOM assigned at certification of 7.620 kg; the aircraft can transport from 6 to 9 passengers, according to configuration and mission type.
It's equipped with 2 turboprop Pratt&Whitney Canada model PT6C-67A engines of 1.940 shp each.
Aircraft N609AG (S/N 60002), also called "AC2", had been authorized for test flights to develop the project from ENAC, with a dedicated protocol (number 0077827) renewed on the 20th of July 2015 and referring to the Special Airworthiness Certificate issued by the FAA (number 004230669) on the 15th of July 2015, expiring on the 14th of July 2016.
At the day of the accident, tha aircraft had flown a total of 567h 30'.

History of the project.
The aircraft project, initially called BB609 Tiltrotor, was developed by Bell Helicopter Textron Inc. (BHTI) and by Boeing in the early 90's. In 1998, Bell and Agusta entered the joint venture Bell-Agusta Aerospace Company (BAAC), that administered the BA609 until november 2011. After this, Agusta US Inc. which later was named AgustaWestland Tilt-Rotor Company (AWTRC),

acquired the full property of the project. The BA609 Tiltrotor was therefore renamed AW609.
On the15th of February 2012, the AWTRC presented a request to the FAA for the civil certification of aircraft AW609, as a follow up of the development program of the BA609, referring also to the cooperation plan FAA/EASA regarding the Tiltrotor project. The AWTRC became the new applicant for the civil certification to the FAA; the request to EASA was performed to validate the certification in the EU.
On the 1st of January 2015 the AWTRC merged in the AgustaWestland Philadelphia Corporation (AWPC), subsidiary firm of Leonardo.

Aerodynamic tests in the wind tunnel were performed by Bell at Texas A&M University (TAMU), using a model, in the period comprised between august and december 1997.
The most significant changes from the configuration used for the tests were represented by the reduction of the tail fin and the tapering at the end of the fuselage; these changes involved a modification in the structure of the aircraft (figure 2) were introduced on aircraft N609AG (prototype 2) from August 2013 (test flight 468) and on prototype 1 from November 2014 (test flight 1015).
No experimental tests result have been performed in the wind tunnel for this last configuration, as the new design has been validated with computational fluid dynamic (CFD), analytical simulations and a dedicated flight test campaign between 2012 and 2014, with the collaboration of Bell helicopters.

Over 1300 hours of envelope expansion and developmental flight testing was performed since 2003, including over 100 test conditions in airplane mode dive speed conditions, creating a vast database of aerodynamic, stability and control characteristics. A flight test squawk process is used to identify and analyse test results which do not comply with requirements, show unexpected characteristics, or are deemed questionable by flight test pilots or flight analysists.

Flight Control System (FCS).
The FCS system of the aircraft is composed by: standard control systems in the cockpit (FFC, fixed flight controls) represented by control stick, pedals and thrust lever; 3 FCC; sensors; hydraulic and electrical systems; actuators. These systems, in combination with the flight control surfaces and the interface with the engine controls, allow the pilots to control the passage from helicopter to airplane mode, to control the flight profile of the aircraft and to manage the requested engine power. The FCS was designed as a fly by wire system, that employs a redundant architecture via three flight computers, that handle the various inputs given by the various aircraft sensors and the FCC, in order to apply the control

laws (algorithms to control the aircraft), that are pre-programmed in a software that acts on the control surfaces and on the actuators of the proprotor.
The FCS is also responsible in transmitting force feedback to the pilot's controls via actuators as there is no mechanical link between the FFC system and the hydraulic actuators in a fly by wire system.
Via the FFC of the AW609 the pilot has control on the three axes of the aircraft and on engine power of the proprotor. The flight control of the modality airplane/helicopter is obtained via a command cyclic-collective on the proprotor, on the elevator (on the vertical empennage), on the flaperons (ailerons-flaps on the wings) and on the command of the nacelle inclination angle.
Even though the cockpit controls are the same for both aircraft flight modalities, the mechanisms that actuate the control effectors are different. In particular, in the airplane modality (nacelle at 0 degrees of inclination) the control on the lateral and longitudinal axis is actuated by the flaperon and by the elevator, whereas the directional control is actuated via the DCP, based on the difference in the collective pitch of the blades of the two respective proprotor with the inputs given by the pedals and stick in the cockpit (figure 2a).

Maintanance.
The aircraft resulted maintained in accordance with all the applicable procedures. The last maintenance resulted carried out in September 2015 and it concerned the 80 FH periodic safety inspection, which had been performed following flight test T650 without encountering anomalies. After flight test T661, in October 2015, two non programmed interventions had been performed, regarding the substitution of the windshield (due to diminished visibility caused by part aging) and the substitution of the V-block P/N 609-032-313-101 (having reached wear limits): it constitutes the mechanical stop to the rotation of the nacelles at 0 degrees. Both interventions do not present elements related to the accident dynamics.

Information on the place of the event

The three main parts of the wreckage were located around 1,8 km N-W of the city of Tronzano Vercellese (VC), in a field cultivated with corn crops. Many pieces of the aircraft were found on the ground spread along a portion of terrain of around 100-300 m of width and 2 km of length, to the south of the city of Santhià (VC), on agricultural terrains and residential areas. (figure 1a).

Meteorological information

The meteorological conditions at the moment of the event did not present critical elements related to the accident dynamics.
The METAR at the airport of Milano Malpensa (LIMC) before departure stated: METAR LIMC 300920Z VRB02KT CAVOK 16/11 Q1025 NOSIG.

Other information

Previous events.

On the 17th of July 2014, during test flight T573-R34, simultaneous high values of AOA, AOB, MN, rate of descent and number of “g” caused an accelerated stall of the aircraft right wing; a significant sideslip developed due to lateral acceleration.

This situation was not fully compensated by the FCS, and caused an excessive flapping on the right proprotor, that induced light contacts of the proprotor itself with the leading edge of the right wing, damaging slightly the leading edge. The crew in that occasion had been able to maintain control of the aircraft and the test flight had been interrupted and ended with an emergency landing on the airport of Venegono (LILN). The analysis conducted evidenced the following contributors to the event:

- the accelerated stall of the RH wing during the wind-up turn, aggravated by the exceedance of the prescribed 2,5g limit (final end point was reached at 2,7g-2,8g with very high AoB and AoA), which caused an increased aircraft asymmetry in the lateral direction plane;
- the persistence of the integral QBAL term of the total DCP command, when the aerodynamic associated with the manoeuvre rapidily changed, which in turn reduced the capability of the directional DCP term to promptly compensate for the yaw excursion.

The corrective actions that followed established limitations in the flight envelope (to avoid the same flight conditions to be encountered again) and procedures: a new parameter (QBALTH) was added to the ones displayed on ground (via telemetry) and in flight, to be continuously monitored; for value between 0,7 and 1, an amber message appears on the EPDU, with no crew action required, in case the value exceeded 1 the message appears in red. In case the QBALTH value exceeded 1 out of straight and level conditions and especially during asymmetric manoeuvres, the test had to be interrupted and the aircraft smoothly levelled.

Testimonies.

Eyewitness 1.

A person, who was working inside the dismissed electric plant “Galileo Ferraris”, located 11,85 km S-SE from the point of impact of N609AG, observed the aircraft flying with a nearly level attitude with a slight wing inclination to the left, when a sudden explosion in flight disintegrated the aircraft itself, its remains on fire falling parabolically towards the ground. The witness in question shot photo 2, as attached.

Eyewitness 2.

The witness in question, who had worked previously as an airline pilot, was in the city of Santhià at the time of the accident.

This witness reported to having looked skywards after hearing the noise of a low level flying aircraft; the aircraft was flying with a nearly level attitude while slightly pitch down. He noted, at the same time, the presence of grey smoke coming from the wingtips. He reported having observed a first bank towards the left, without high angular speed. When the aircraft assumed a 40° bank, flames started to develop immediately followed by an explosion that disintegrated the aircraft. The witness reported: «La parte più grande, avvolta da fumo nero, è precipitata quasi in verticale (parabola con cupola molto ridotta, nella direzione del moto), mentre molti rottami più piccoli e leggeri, fumanti, meno uno ancora incendiato, sono caduti al suolo più lentamente, ed in un raggio più ampio, il cui baricentro sembrava essere il relitto più grande e pesante.» [translation: the witness having seen the greater part of the wreckage enveloped in black smoke precipitating nearly vertically, with a trajectory similar to a parabola with a cupola very reduced in the direction of motion; many smaller and lighter smoking parts, apart from one still flaming, fell to the ground slowly and in a wider range.].

Wreckage and impact information.

The main points of impact and the final position of the aircraft fuselage (from the nose section to the tail fin) were localized on an agricultural terrain, in a uninhabited area, 1,8 km NW of the city of Tronzano Vercellese (VC) at the following coordinates: N 45 21'.24 E 008 09'.22.

The fuselage (photo 3) constituted mainly of carbon fibre appeared substantially burnt, with evident signs of impact on the ground and upturned, whereas on great part of the tail fin evident signs of exposition to high temperatures were present.

The two nacelles, with an attached portion of the wings and the six proprotor blades, (three for each proprotor) were localized at a small distance (between 66 and 111 m) from the fuselage, in the same terrain; both showed evidences of fire and deformations by ground impact and with the blade roots of the proprotors still in place. (photo 4 and 5).

Other traces of impact were not found around the represented coordinates, apart from the three craters beneath each above mentioned part, generated by ground impact; this brings to determine that the aircrafts trajectory respect to terrain in the last instants of flight coild be mostly vertical.

In the days following the accident, during the accident site inspection conducted by the investigation team of ANSV (assisted by personnel of the aircraft manufacturer and by Public Safety personnel), a map of the aircraft wreckage was created and the debris were geoloclalized on the ground; this map is coherent with the aircraft trajectory, achieved initially by the radar plottings and then confirmed by FDR and FTI data (figure 3).

The results of this map evidenced a wreckage distribution area with a section of a width of around 100/300 m and a length of 2 km, South of the city of Santhià (VC).

The distribution of the debris, together with photographical evidence, is coherent with a structural breakup in flight, which then caused an explosion and ballistic trajectory towards the point of impact on the ground.

The lighter debris (mainly the blade extremities and their structure) are prevalent in the first part of the final trajectory and spread along a vast area. The heavier parts were instead concentrated on a less vast portion of terrain, between the city of Santhià and the A26/A4 motorway E25 branch.

Some of the local inhabitants signalled that people had been seen picking up some small parts immediately after the accident, thus modifying partly the place of the event.

Excluding the fire that burnt the fuselage once on ground, documented by various videos and photos taken by local people, other fire evidences on the ground have been found in the field immediately surrounding the left nacelle (together with part of the wing attached). This evidence is coherent with the presence of fuel in the bladder tank (fuel tanks) still inside the wing torsion box, which could have still had a considerable amount of fuel Jet-A1 contained inside at the moment of impact with the terrain.

Around the right nacelle no signs of fire on the ground were found: the corn crops appeared intact.

In this regard, the photographic evidence found shows that during the descent parabola, the right nacelle was wrapped into flames. It is therefore reasonable to assume that the in-flight fire has burned all the fuel present into the right nacelle, thus making it impossible to propagate the fire once on the ground. Unlike what happened to the left nacelle, the bladder tanks were not found, but they were found together with the rest of the right half-wing.

The vertical empennage, comprising the tail fin, presented evident signs of high temperature exposure, presumably in the last instants of flight.

Flight Test Instrumentation (FTI).

The aircraft AW609 registration marks N609AG was equipped with an high number of sensors able to register more than 6800 parameters with acquisition frequencies up to 3000 Hz on 2 non-volatile memories and also the audio coming from the ICS.

The memories on which this data was recorded were not protected and went completely destroyed in the accident following the impact with the ground and the temperature caused by the fire generated in flight and after impact.

Two cameras were also installed on board, one in the cockpit and one on the tail fin. The video images coming from this apparatus were recorded on a video recorder (DVR) equipped with an unprotected magnetic disc. The video recorder, even though extremely damaged, was salvaged in an attempt to acquire data; however after technical analysis performed on the component, it resulted destroyed. (photo 6).

Telemetry.

Part of the data recorded by the FTI, 2973 of 6800 parameters, and the recordings of the communications ground-on board-ground and cockpit were transmitted in real time to the ground station. The manufacturer made this data immediately available in the hours following the event.

Multi Purpose Flight Recorder (MPFR).

The aircraft AW609 N609AG was equipped with a combined protected flight recorder FDR/CVR-MPFR Penny&Giles P/N D51615-102. This had been configured to record external and cockpit internal communications, environmental sounds and 420 parametres with an acquisition frequency between 0,25 and 8Hz.

Following the accident, the unit presented visible impact damage (photo 7) and so it was necessary to open the recorder and extract the memories in order to directly read them. This activity, unrepeatable regarding the mechanical extraction of the memory units, was performed in two sessions in the laboratories of ANSV, coordinated with the competent judicial authorities and in line with what is foreseen in EU regulation n. 996/2010. In the first session the flight recorder was mechanically opened and the memory units extracted. In the second session some precautionary electrical tests were performed before proceding with the following and definitive download of all data present in memory units. The raw data obtained was then converted into engineering units and made available to the safety investigation, which analyzed numerous parameters.

During FDR analysis, it emerged that some fundamental parameters (such as an example latitude/longitude and ground speed) had not been recorded. Regarding this, it must be said that for experimental aircraft it is not mandatory to have a flight recorder installed on board.

The presence of the MPFR, even though not yet fully set up, was ascribable to an initiative of the manufacturer, considering that a full FTI plus a DVR were already installed for project development purposes.

Evidences obtained by the recorded data.

<u>*Audio tracks by CVR.*</u>

The analysis of the CVR data demonstrated a normal and efficient procedural and communication flow from takeoff to some minutes before the accident.

In particular, the mode of execution of test flights involves continuous coordination between the in-flight crew and the test director present in the ground station; he is also supported by additional technical personnel in monitoring the complete sets of experimental parameters.

The crew, after the second dive, noticed that the message “PRGB#2 DAMAGE” had illuminated and communicated this fact to the ground test team. The message was received and the test

director advised that the warning message could have been real, but it was used only to highlight strain levels of the PRGB; however, he put the crew on stand by to check other data.
The crew commented that it could be an already known issue and continued the flight. After about a minute, the test director confirmed to the crew that they could proceed with the following test. After two minutes, while the plane was accelerating through the third dive, the PIC, that was also PF, started to perceive unusual oscillations in roll and yaw («Man, roll, and yaw!», CVR source at t=21,1 sec. from the beginning of R20); the PNF intervened saying «It's OK» (CVR source at t=26,1 sec.). After that, the message on the EPDU: "QBALTH" lighted and the PF instructed the PNF to stand by on actioning the perturbation[1].
After about 5 seconds, the PNF said «Pull it up, pull it up!» (CVR source) in an alarmed manner; at the same time the first proprotor came into contact with the leading edge of the right wing and the aircraft started to become irredeemably uncontrollable.
The CVR reported the sounds of the following explosion, the warning sounds inside the cockpit and the last comments of the PF regarding the unusual flight attitude of the aircraft («Look at the attitude, look at the attitude!», CVR source).

Flight data.
The data recorded by the MPFR and, when not sufficient in quantity and/or precision, the data coming from the FTI sent in streaming (telemetry), was used to obtain the necessary evidences for the safety investigation. In detail, a systematic study was conducted on the functionality of each system.

- *Proprotor.*
Proprotor dynamics during the accident were reconstructed by observing the evolution of the deformations on the stops of the flapping of the proprotors (figure 4) and blade deformations and accelerations (figure 5 and 6); in particular, an excessive flapping of the right proprotor occurred during phase R20 of flight T664, that induced contact between the wing and the proprotor itself. Analysis of the telemetry data including an accounting for instrumentation delays indicates that this event occurred at t=33,1 sec. (up to t=33,4 sec.) from the beginning of phase R20. The same phenomenon occurred for the left proprotor between t=35,1 sec. and t=35,4 sec.
The excessive flapping was caused primarily by the sideslip angle reached by the aircraft, that exceeded, nearly two and a half times, the maximum flight envelope value at the speed of 293 knots (10,5 degrees as opposed to the 4 degrees maximum allowed) (figure 7 and figure 7a).

[1] The perturbation consisted in a longitudinal cyclic pitch symmetrical solicitation induced by the proprotors, amplitude 0,1° and frequencies from 4,5 Hz to 4,8 Hz.

- *Engines and transmission.*

The main engine parametres have been investigated to verify their correct functioning. No anomalies were observed until the contact between the right proprotor and right wing. In figures 8 and 9 the following parameters are reported: torque, oil pressure, oil temperature, power turbine speed, proprotor speed and gas generator speed. Furthermore, from data it is evident that the engines continued to run even after proprotors impact.

In particular, the analysis of the torque value on the right and left engine reflected the already known aircraft asymmetries, which were always minimal. This brings us to believe that the transmission was working correctly until the time of impact of the right proprotor with the right wing and this hypothesis is confirmed by the distribution of the debris: a fragment of the ICDS was found along the distribution line in the direction of motion after fragments of the right rotor and right wing (photo 8, fragment ICDS).

- *Hydraulic System.*

The AW609 has three independent hydraulic systems, that erogate a pressure of 3000 PSI. These systems functioned correctly until the first contact between the right proprotor and wing (figure 10). In detail, for the hydraulic system (figure 10a), due to the location of the tubes (figure 10) it's evident that the failure of systems 1 and 2 was the direct consequence of the interference between proprotors and wings. For system number 3, it's feasible to consider that the acellerations subjected by the nacelle, following the contact between proprotors and wings, had induced the disconnection of the pipes.

- *Electrical system and avionic units.*

From data it is possible to observe that the three electrical generators gave the requested values of voltage and amperage until contact occurred between the proprotors and wings (figure 11). In the moment t=46,1 sec. when the voltage went under the foreseen value, the electric system started feeding automatically from the battery.

The output signals of the avionic system that equipped the aircraft (substantially made up of the units AHRS Type LCR-110, ADAHRS Type LCR-300A and AIR DATA SYSTEM Type AC-32) represent the input of the three FCC (from figure 12 to figure 17) and have been compared to verify their coherence. The electrical power has been guaranteed by the system for the whole flight and even after the contact between proprotors and wings.

- *Mobile surfaces and structure.*

The study of telemetric data has evidenced that the aircraft mobile surfaces had detached due to the anomalous loads generated during the accident. The only exception was the vertical stabilizer, which was still attached to the fuselage after the accident.

- *CAS Messages (Caution Advisory System).*
During test flight T664, from aircraft start up, three CAS messages activated:
1. Primary Anti-Ice System Failure;
2. Secondary Anti-Ice System Failure;
3. LH Bleed Air Leak.
The first two are relative to the absence on the aircraft of an anti-ice kit. The third is linked to an already known sensor defect that of which there was no replacement at the time of the flight. The bleed pressure values were recorded by telemetry, and did not evidence any anomaly.

- *Other messages.*
During test flight T664 the message “STDBY ADS FAIL” also activated; this message is linked to the accuracy difference between the Standby Air data System and the other two air data systems. Specifically, it has been found that this discrepancy would have activated the CAS (STDBY ADS FAIL) in conditions out of the flight envelope, which led to a miscompare between three air data systems; furthermore, the message can be reset by pilot action once back in normal aircraft flight conditions.
The Standby Air data and Attitude System is triply redundant and single-fail operational as used for FCS gain scheduling; because none of the other two platforms had experienced a failure, it is believed that this temporary message did not indicate an anomaly linked to the event.
To be noted that at the end of the preceding dive (R19) the amber “PRGB#2 DAMAGE” had appeared on the EPDU. The manufacturer had introduced this specific message, relative to the right proprotor gearbox, in the software, because before the accident some cases of fatigue cracks had been recorded that had produced some small oil leaks. The activation of the amber message “PRGB#2 DAMAGE” did not require any procedure by the crew (see table 1). However it was considered important for project development to record the vibration level of the apparatus, in order to correctly calculate the long-term fatigue life of the component. This because even if a small crack had been present the consequence would have been just a small oil leak.
Between instant t=24 sec. from the beginning of R20 test of the test flight T664 to about t=30 sec. the activation of the amber message “QBALTH” on the EPDU was registered.
When this value increases the authority of the integral branch of the directional control logic (which acts as a trim) is close to overcome the authority of the remaining branches (for example: FCS stabilization and pilot command), allowing the full pedal authority about the slow moving dynamic of the QBAL; the two authorities are identical when QBALTH is 1. As already stated, for QBALTH values of more than 0,7 and less than 1 the message is amber, and for values equal or greater than 1 it’s red. In the

temporal interval described the message resulted amber (value exceeding 0,7).
Some instants before commencing test R20, and for about 27 seconds, a flag activated on the telemetry management software, regarding the parameter coded 80JKU1. To this was associated the description “Coupled mode/Avionics Discrete WD 1 – Lateral Axis Fgc Fail”. This discriminant parameter has a real meaning if the flight guidance computer is present, that was however not implemented on the aircraft. Its activation was linked exclusively to performing a bank with a roll of more than 35 degrees. This message, visible only on one of the control panels of the ground station, resulted therefore spurious and linked to a non-coherent configuration in respect to the effective one of the aircraft.

- *Flight Mechanics.*
The recorded data allowed the study of the mechanics of test flight T664 and of the orders given by the crew.
The foreseen test operations consisted in setting the aircraft in stable flight conditions at a CAS of 293 kts, and then to insert the perturbation; after that, a climb recovery was expected.
The accident occurred in correspondence of the third dive manoeuvre, in which a maximum CAS was reached (FDR data) of 306 kts (figure 18). In the preceding manoeuvres a CAS of 303 kts (in the first dive) and 295 kts (in the second dive) had been reached. The foreseen test point was reached at 293 kts, after which the perturbation insertion was to be activated and in the following instants the attitude of the aircraft was not to be modified. However, in the third dive, the flight crew actions, executed in attempting to resolve the controllability issues and described below, had allowed a higher speed increase.
Also to be noted that test flight T664, discussed and planned during a preflight briefing by the crew, was the first flight in which such speeds had been reached in the new configuration of the streamlined fuselage in the tail and a reduced tail fin surface. This approach was followed because the previous flight tests (flown up to 285 kts on AC2) and the analysis performed by the manufacturer did not highlight any different behaviour between the two tail configurations within the angle of sideslip design envelope.
The third dive, test R20, was commenced during a left 180° turn. After rollout, a slight lateral-directional oscillations have begun to develop (roll at t=4 sec. and yaw at t=5 sec. and further on) such as to cause an “out-of-trim” condition by the FCS developed (figure 19).
At such oscillations, the crew did not initially react with inputs that were in contrast to them. Later, when the oscillations became greater (t=23.4 sec.), this phenomenon was initially contrasted with counterphase input roll manoeuvres by the PF (roll tracking) and finally by pedal inputs, at t=27.5 sec., to contrast the yaw oscillations. However these actions did not dampen the oscillations, which instead became divergent, bringing the sideslip

angle to reach values above the maximum allowed in those speed conditions (figure 7a).

SIMRX (project simulator).

The SIMRX is the flight simulator developed for the aircraft AW609 and was designed in order to:

- study the aeromechanical behavior and develop control laws;
- FCS development, certification and laboratory testing;
- support to flight test for pilot familiarisation and risk reduction.

After the design modifications made on the rear part of the fuselage and on the tail fin, which resulted in a change in the structure of the aircraft, the SIMRX was updated to take into account the CFD and flight test campaign between 2012 and 2014 specifically performed to clear the new configuration.

During the safety investigation, an investigation team by ANSV went to AgustaWestland Philadelphia Corporation, where various flight profiles were examined on the project simulator of the aircraft. This activity was performed together with technical personnel and a pilot of the manufacturer in order to acquire and examine, in particular, project elements of the software comprising the control laws acting on the FCS and of the aerodynamics associated with the digital model of the aircraft.

With the SIMRX configured in the same software and flight conditions of the accident, however it was not possible to reproduce the conditions occurred during the accident.

In order to reproduce flight conditions similar as much as possible to those of the accident algorithms were inserted, that would have however greatly modified the real aerodynamic configuration of the aircraft; only with this configuration of the SIMRX it was possible to develop lateral-directional oscillations (albeit with a different phase with regard to the accident flight) and verify the great difficulty of an eventual recovery back to controlled flight conditions of the aircraft.

Analysis

This event investigated by ANSV is characterized by two peculiar aspects: the aircraft complexity (experimental protoype in its design development phase) and the operative environment in which the accident took place (test flight reaching the maximum design speed).

On the basis of the gathered evidences, the aircraft – during test flight T664 and while recording data on test R20 (third dive) – after having encountered uncontrolled flight conditions due to latero-directional oscillations, suffered an in-flight breakup, followed by a fire and next by the impact of its remains on the ground.

The geolocalization of the debris on the ground, their specific nature and the condition in which they were found allowed to establish a sort of pathway, which can be seen as a ground projection of the descendent trajectory made by the aircraft in the last moments of flight. Considering that the flight trajectory was towards West, the localization of the proprotors blades debris in the Southeast part of the city of Santhià was in fact followed by the debris of the aircraft structure (wings, tail fin and fuselage).
The study of the recovered information from the onboard recordings allowed understanding how the impact of the right proprotor and afterwards of the left one with the respective wings occurred during T664-R20. These events are perfectly traceable in time and space thanks to the data analysis coming from the sensors that were on the proprotor blades.
All on board systems resulted functioning correctly until the impact event, and this is confirmed by the debris distribution that shows in sequence first parts of the right rotor and right wing, and then all the other parts. The only exception in the distribution map are light parts of filler present inside the blades. These were subjected to the propelling force of the rotor flow, and also of air currents possibly present at the time of the accident and in the following hours.
The study of the CAS messages and other messages in telemetry brought to consider that these warnings were not linked to the accident, except for the amber message “QBALTH” that activated on the EPDU: this indicates the measurement of the residual quantity of pilot authority on the directional control of the yaw axis, and it was activated during the latero-directional oscillating phenomenon.
In detail, from the data coming from the MPFR it was evident how the oscillation started on the roll axis following the exit from the turn (from t=4 sec. and further on), that had the scope of repositioning the aircraft in the direction for the third dive with wings level. To the initial slight oscillation in roll another one was added shortly after in yaw (from t=5 sec. and further on, also initially slight); at such oscillations, the crew did not initially react using inputs to counteract them.
This condition is confirmed by the CVR data: at t=21 sec. from the beginning of R20 the PF comments in fact the combined presence of oscillations in roll and yaw («Man, roll and yaw!», CVR source).
In that moment, the oscillations are present in greater magnitude and the PF starts to act in inpts of “roll tracking” (intervention with the flight controls on the longitudinal axis), as a standard pilot procedure for this type of condition. After this the PF acted also on the rudder pedals, observing a pronounced yaw condition.
The manoeuvres performed did not have however the effect of dampening the oscillations, that instead increased bringing the sideslip above the maximum values and so inducing contact of the right proprotor with the right wing due to the excessive flapping

of the proprotor blades. According to the aviation literature, this phenomenon could be also classified as APC (Aircraft Pilot Coupling).
The analysis performed by the manufacturer about this oscillating phenomenon evidenced how this was present in other previous test flights, even though recognized as self-damped.
This behavior was probably known to the crew that, as previously mentioned, from the initial phase of the oscillations (from t=4 sec. to t=23.4 sec.) did not act any input to counteract.

The reason because the manoeuvre executed by the PF from t=23.4 sec. and further on did not produce the desired effect, the damping of the oscillations, is to be found in the combined effect of the following factors:

- the specific high speed dive test condition;
- the aircraft flight dynamics and aerodynamics characteristics;
- aircraft structure;
- the control laws of the aircraft.

More in detail, in the accident flight the test was performed for the first time at dives reaching the speed of 293 kts, with a tapered structure at the rear of the fuselage and with a reduced fin surface. This speed represented the V_D (design dive speed, which is the maximum theoretical speed reachable into a dive) and so the test represented a trial performed in boundary conditions.

The tests performed by the manufacturer via the project simulator SIMRX and other test flights performed in similar conditions were considered sufficient, by the same manufacturer, to perform the T664. Anyway, the test on SIMRX would have not been representative, at high speed, of real aircraft behaviour, as confermed also by ANSV verification on simulator, possibly due to unexpected aerodynamic characteristics in this extreme flight condition of speed, having extreme: AOA values, flaperon deflection angles and elevator deflection angles.
This condition happens, in particular, for cross-coupled sideslip and roll (example: left sideslip/right roll).
The fact that tests on the SIMRX were not representative of the actual aircraft behavior is reasonably due to the lack of experimental data obtained previously in the wind tunnel and in-flight evaluations with those speed conditions and relating to the recent modified geometry configuration of the tail fin; this last change was considered conservatively by entering a reduction in the tail fin area into the database and then implementing the computational fluid dynamics (CFD).
It’s probable that the boundary conditions that were foreseen for the execution of the T664 made the latero-directional oscillations, already registered by the manufacturer in other situations, more persistent.

The intervention of the PF resulted in line with what is correctly possible to do in such circumstances. However the control laws of the aircraft, actuated via the FCS are such as to couple on more axes the command inputs given on the single axes by the pilot: a roll command is transferred by the control laws into different commands that are sent to the control surfaces that act on the roll (for example: flaperons) and to the differential collective pitch control, that, in this aircraft, regulates yaw.

Total lateral control resulting from the summation of pilot input and automatic FCS input has an effect on the yaw axis through aerodynamic coupling and feedforward and feedback turn coordination inputs automatically provided by the FCS.

When a flaperon is deflected for example to roll left (right flaperon down), the flaperons produce a downwash on the right and an upwash on the left side. This creates a sort of swirl resulting in a sidewash on the fin (flow coming from the left) and induces a nose left yaw, in the same direction of the roll, known as "proverse yaw". The FCS control laws include a feedforward command to compensate for this aerodynamic coupling effect.

Consequently, giving a command in counterphase on the roll axes to dampen the relative oscillations creates an effect on the yaw axes that can be in phase with the yaw oscillations. This occurred during the accident: the correction of the roll oscillation induced, by the control laws of the FCS, a manoeuvre in phase with the oscillations on the yaw axes, generating the divergence of the oscillations.

Therefore, due to the aircraft structural factors (intended as shape and rigidity) and the flight conditions, the aircraft developed lateral-directional oscillations; the low frequency and low amplitude nature of the oscillations made them difficult to perceive by flight crew and test team on the ground or such that they can be assimilated to those already known being self-damping.

This phenomenon was involving two different control axes and developed at very low frequencies, resulting in a difficulty to be acknowledged by the pilot or by the ground crew until the roll and yaw magnitude reached excessive levels which was only a few seconds before loss of control.

The human factor analysis based on the CVR data showed a normal and eased pace in the communications between the flight crew and the ground station (test director) up to the post-recovery phase from the dive R19, when the PF announced the message "PRGB#2 DAMAGE" light, and as a matter of fact, he wanted to get the attention of the other crewmember and passed the information to the ground station.

The test director takes in account the announced amber light and told the PF to «standby» (CVR source), and that he had to do some checks probably to diagnose the indication and determine the

proper course of action. In the minute following the notification, the crew evaluated internally and in tranquillity the message as «an old issue» (CVR source), whereas the test director then communicated that they could continue with the following test without giving a "feedback" on the checks that he made; this flow of actions does not seem to have represented a contributing factor for the outcame of the next events in the flight, and for the accident, but could be traced back to customary operations between the flight crew and the ground station team.
In this respect, it would seem appropriate to point out that there are substantial differences between the procedures in the course of carrying out the commercial flight operation and those in operation during the test flights relating to prototypes of aircraft during the certification phase. In this latter type of activity, in particular, the conduct of the flight crew and the staff of the ground team following the flight test, is not precisely coded in every single aspect, due to the often atypical characteristics of a flight test.

The debris mapping on the ground, the analysis of the evidences and of the data given by telemetry and by the MPFR bring us to hypothesize with reasonable certainty that the cause of the in-flight breakup was the consequence of multiple contacts of the proprotors with the aircraft wings, due to excessive yaw angles reached during the third high speed descent. The impact of the proprotors on the wings, given by excessive blade flapping, damaged the hydraulic and fuel lines that are positioned on the leading edge of the wings (figure 10a), causing the in flight break-up followed by the fire. The aircraft is equipped with flapping stops: however this stops are not designed to contain the effects of the extreme aerodynamic forces that generated during the event.
The available testimonies find reasonable validation in the analysis of the dynamics in the last flight moments of the aircraft and contribute in defining what has been elaborated.

Causes

Considering the gathered evidences it is possible to believe that the cause of the accident is basically ascribable to the combination of three factors:

- to the development of latero-directional oscillations;
- to the FCS control laws unable to maintain conditions of controlled flight;
- to the project simulator (SIMRX) which did not foresee the event in any way.

In detail, the aerodynamic characteristics of the aircraft and the specific test flight conditions in a high speed dive are factors that have created a condition in which the aircraft has developed latero-directional oscillations, subsequently amplified. The PF tried to counteract this oscillatory condition using a roll tracking manoeuvre reasonable in order to level the wings for the test condition.

The FCS control laws, in "airplane mode", always associate to a roll input an action on the control logic acting on the yaw; these yaw control inputs were in phase with the oscillations currently in course on this axis. In detail, the pilot roll input was counter phase but the control laws resulted in an in-phase amplification of the yaw oscillations, making them divergent until the proprotors contacted the respective wings, causing great structural damage followed by an in-flight break up of the aircraft with subsequent fire.

The project simulator (SIMRX), used for the development of aircraft certification, is partly based on the predictive capacities of the aerodynamic models integrated in the project simulator itself. The new tail and rear fuselage designs have been previously cleared by analysis and flight testing, and SIMRX was consequently updated. However, as evidenced by the tests carried out by the ANSV, the simulator demonstrated not being able to faithfully reproduce the dynamics occurred during test flight T664 R20, reasonably due to the non-representativeness of the aerodynamic data set, for the unique and extreme conditions encountered, obtainable in the wind tunnel for the new updated configuration including the tapered rear fuselage and the modified tail fin. Therefore, the SIMRX was not really able to properly carry out the role of test bench for the control laws and risk reduction.

In order to provide a further simplified illustration of the sequence of events and subsequent consequences, some conceptual schemes are included in this report, represented in figures 20 and 21.

Safety recommendations

Considering the gathered evidences and the analysis performed, ANSV during the investigation, in the occasion of the publication of the interim statement, published the following safety recommendations (reference to the photos/figures/attachments mentioned in the following recommendations is relevant to the interim statement).

Safety Recommendation ANSV-9/3173-15/1/A/16.
Motivation: in the accident flight, during the execution of high speed test maneuvering in symmetric configuration, the aircraft AW609 encountered lateral-directional oscillation (picture 2, attached "A"[2] to this statement, roll depicted in yellow and yaw rate in purple, data from the MPFR). The safety investigation showed that this phenomenon was present to a lesser degree also in previous flights. It was considered to be slight and not dangerous, being assessed as self-damping.
Recipients: FAA, EASA.

[2] Picture 2 corresponds to figure 22 of this final report.

Safety Recommendation: the ANSV recommends, in the framework of the certification process, to verify that the aerodynamic behavior of the aircraft at high-speed conditions will be reviewed, if necessary making use of wind tunnels tests in addition to updated models and simulations that can be representative of the complex flight conditions of this peculiar aircraft.

Safety Recommendation ANSV-10/3173-15/2/A/16.
Motivation: in the accident flight, during the development of the aerodynamic oscillation, the PIC tried to maintain the aircraft control (picture 2, input on the roll depicted in green and input on the yaw in blue, data from MPFR). The oscillation that started on the roll axis was corrected by the PIC acting on the roll control, as normally expected. The AW609 flight control laws however are designed in such a way that input on roll axis is generating also a coupling on the yaw axis.
Recipients: FAA, EASA.
Recommendation: the ANSV recommends, in the framework of the certification process, to verify that the control laws of the aircraft will be reviewed in the management of the extreme flight conditions in which the aircraft could possibly fly. That verification should be addressed to ensure the effectiveness of the flight controls inputs given by the pilot avoiding the possibility of unexpected and un-commanded coupling effects.

Safety Recommendation ANSV-11/3173-15/3/A/16.
Motivation: the safety investigation was based in many aspects on data recorded in flight. During the safety investigation it was possible to ascertain that.

- The release of the *Special Airworthiness Certificate* of the AW609AG registration marks N609AG (*category Experimental, Purpose research and Development*) by the FAA was effective with various limitations, listed in the letter of 15th July 2015 by the FAA. Among these limitations, there was no indication about the presence of an FDR on board the aircraft. The MPFR installed on board the AW609 registration marks N609AG was installed on board the aircraft exclusively on the initiative of the Manufacturer. The *Special Airworthiness Certificate* specifies, in section D, that the aircraft AW609 registration marks N609AG is not compliant with the airworthiness requirement enshrined by ICAO Annex 8.

- The *Permit to fly*, released by the Italian civil aviation authority (ENAC) on the 20th July 2015, was released to allow the flight of the aircraft in Italian airspace and it has retained substantially the limitations listed in the FAA letter of 15th July 2015.
- The AW609 is a tiltrotor, which possesses the flight features of an airplane and at the same time the ones of a helicopter. The aircraft is equipped with two turboshaft engines, has a MTOM of 7600 kg, has a crew of two pilots. Once the certification process will be completed, it will carry up to 9 passengers. For commercial aviation airplanes in the same MTOM range, the ICAO Annex 6, part 1, paragraph 6.3, prescribes as mandatory an FDR type II and a CVR capable of recording at least 2 hours. For commercial aviation helicopters in the same MTOM range, the ICAO Annex 6, part 3, paragraph 4.3.1, prescribes as mandatory an FDR type IV A and a CVR capable of recording at least 2 hours (if the airworthiness certificate is released after 1st January 2016).
- There is no mention on the Annex 6 for experimental aircraft, those therefore without anairworthiness certificate consistent with the requirements on ICAO Annex 8.
- However, the experimental aircraft are nowadays often developed by manufacturers whose factories are located in different nations, and conduct test flights in different nations as in the case of the AW609. Experimental aircraft, although they are flown mostly in controlled and reserved airspace, often need to be flown in uncontrolled airspace during the repositioning. In the case of an accident, they might cause damage to third parties on the ground.
- The setting of the MPFR was not such as to ensure the recording of some fundamental parameters for the reconstruction of the flight (as for example latitude, longitude, groundspeed, drift angle). The reconstruction of the flight during the safety investigation was completed thanks to the availability of the data from telemetry.
- The telemetry does not allow a complete and reliable protection of the data in case of an accident, because: the devices used for the recording are not built to be crash-resistant (non-protected units); the telemetry may

undergo interruption in recording or records invalid data in correspondence to particular conditions of the data transmission itself.

– The telemetry could not ensure total transmission coverage during repositioning flights.

Recipients: ICAO.

Recommendation: the ANSV recommends institute as mandatory requirement for experimental aircraft the installation of flight data recorders (FDR and CVR) which, according to MTOM and use, should be anyway equipped with such devices at the completion of the certification process. The number and the list of the minimum required recorded parameters for the experimental aircraft should be the same as the ones required for the equivalent certified aircraft, according to the MTOM and the use. In the case of the tiltrotor, the most conservative solution shall be adopted amongst the requirements for an airplane and a helicopter.

Of the three recommendations issued by ANSV, only two, up to the publication date of this final investigation report, have been acknowledged.

- The one addressed to ICAO (see ICAO letter dated 28 of October 2016, in attachment "B"). ANSV, retaining inadequate the received reply, motivated his disagreement with a letter dated 30 November 2016 (in attachment "B").
- the two addressed to EASA (see EASA letter dated 08 of September 2016, in attachment "B"), considered "open".

The two addressed to FAA were not commented (see email sent to ANSV on 28 September 2016, in attachment "B").

In the process of institutional responses to the above safety recommendations, the NTSB has informed the ANSV that the factualities emerged during its safety investigation and the relevant safety recommendations issued have been used as a reference by the aircraft manufacturer (technical advisor to NTSB on this investigation) to schedule a campaign of extensive new wind tunnel testing and a revision of the control laws.

Attachment list

Attachment "A":	documentation.
Attachment "B":	acknowledgement of safety recommendations.

In the attached reproduced documents the anonymity of the persons involved is safeguarded, according to current dispositions regarding safety investigations.

Attachment "A"

Photo 1: aircraft AW609 registration marks N609AG.

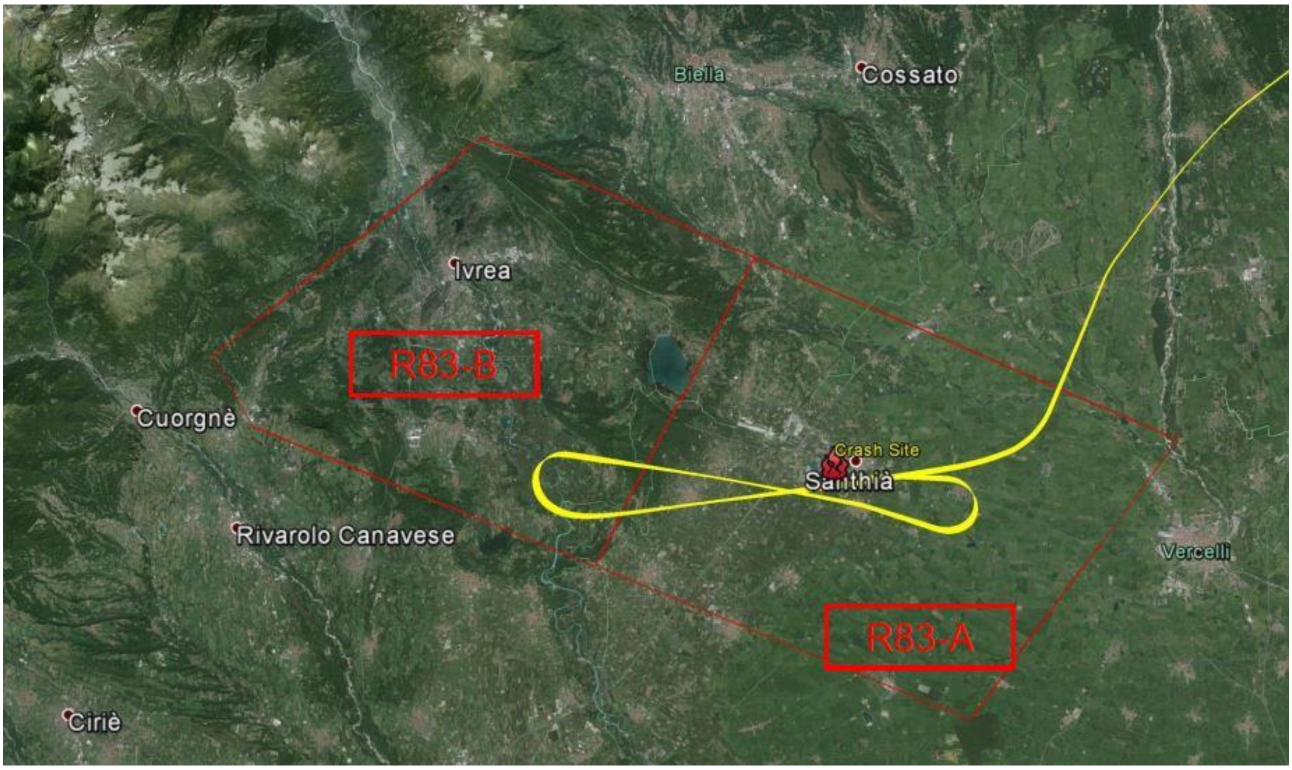

Figure 1: place of the accident.

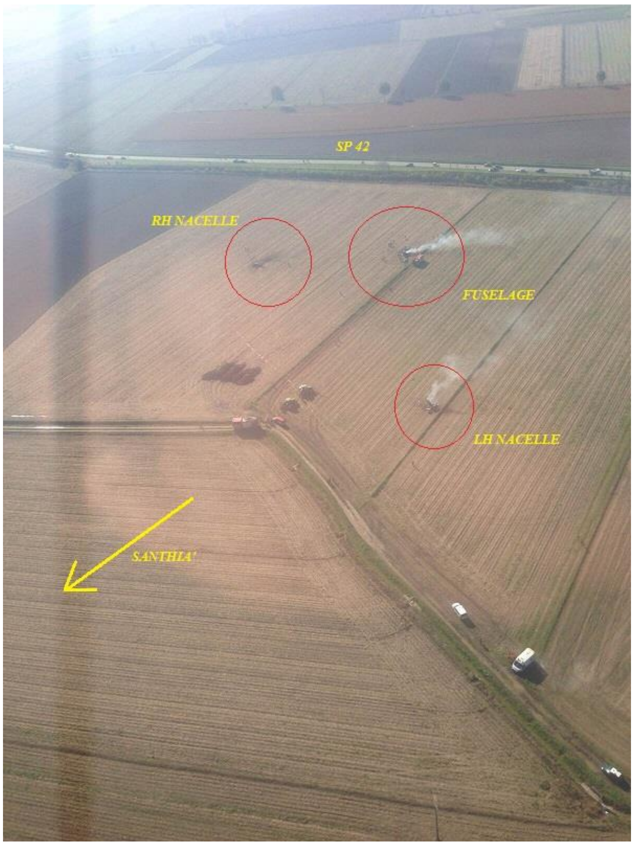

Figure 1a: aerial view of the place of the accident.

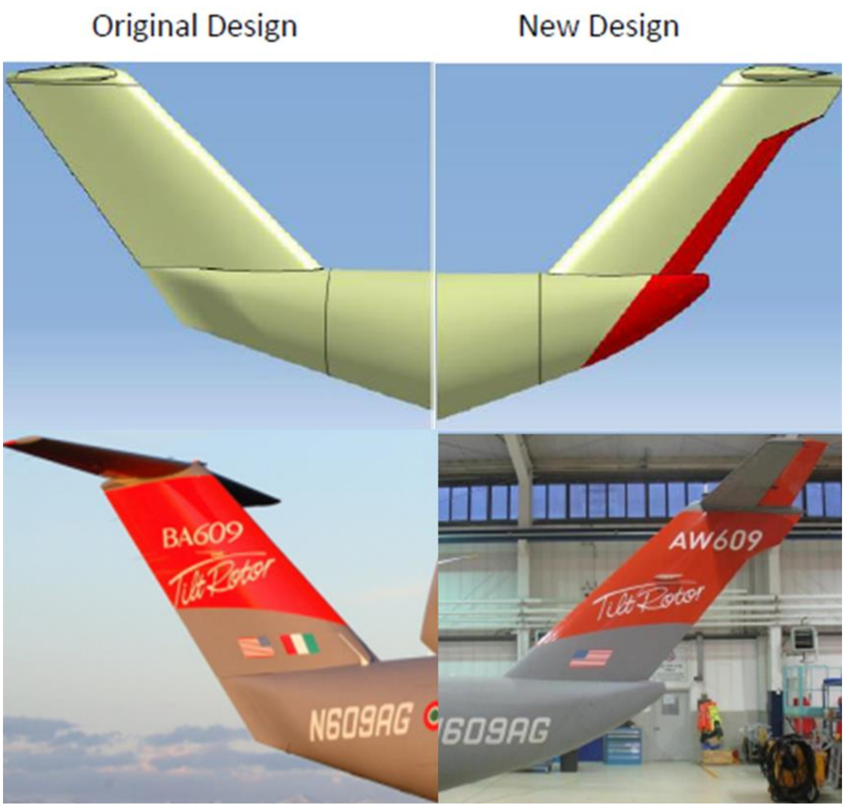

Figure 2: rear fuselage and tail fin structural change

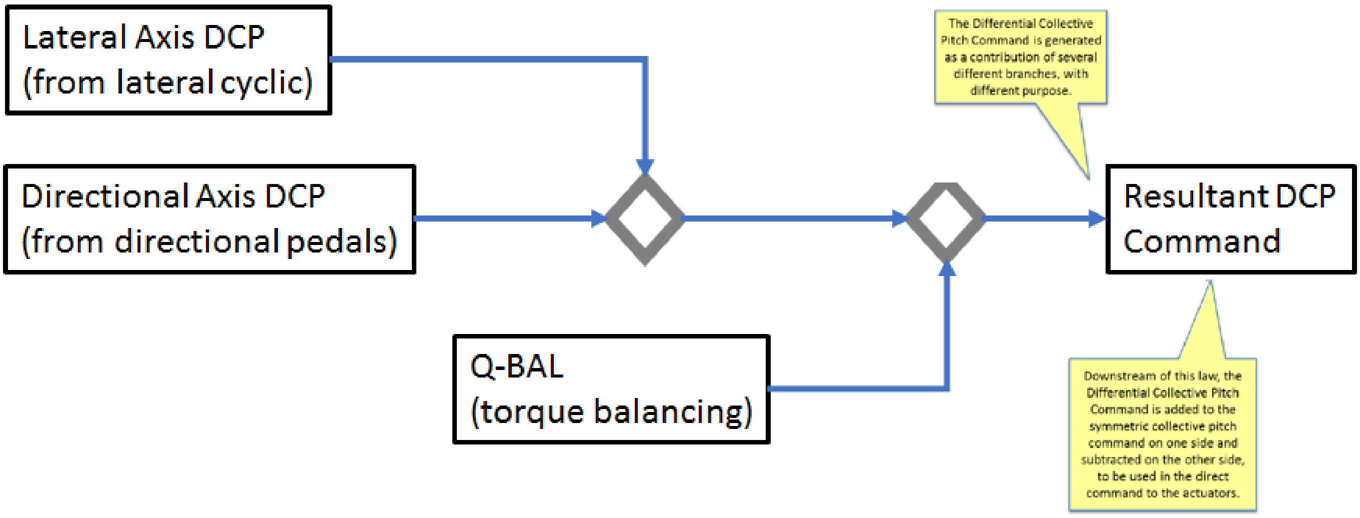

Figure 2a: conceptual DCP Control architecture.

Photo 2: photo taken by a witness positioned by the electric plant "G. Ferraris".

Photo 3: remains of the aircraft fuselage.

Photo 4: nacelle and parts of the left wing of the aircraft.

Photo 5: nacelle and parts of the right wing of the aircraft.

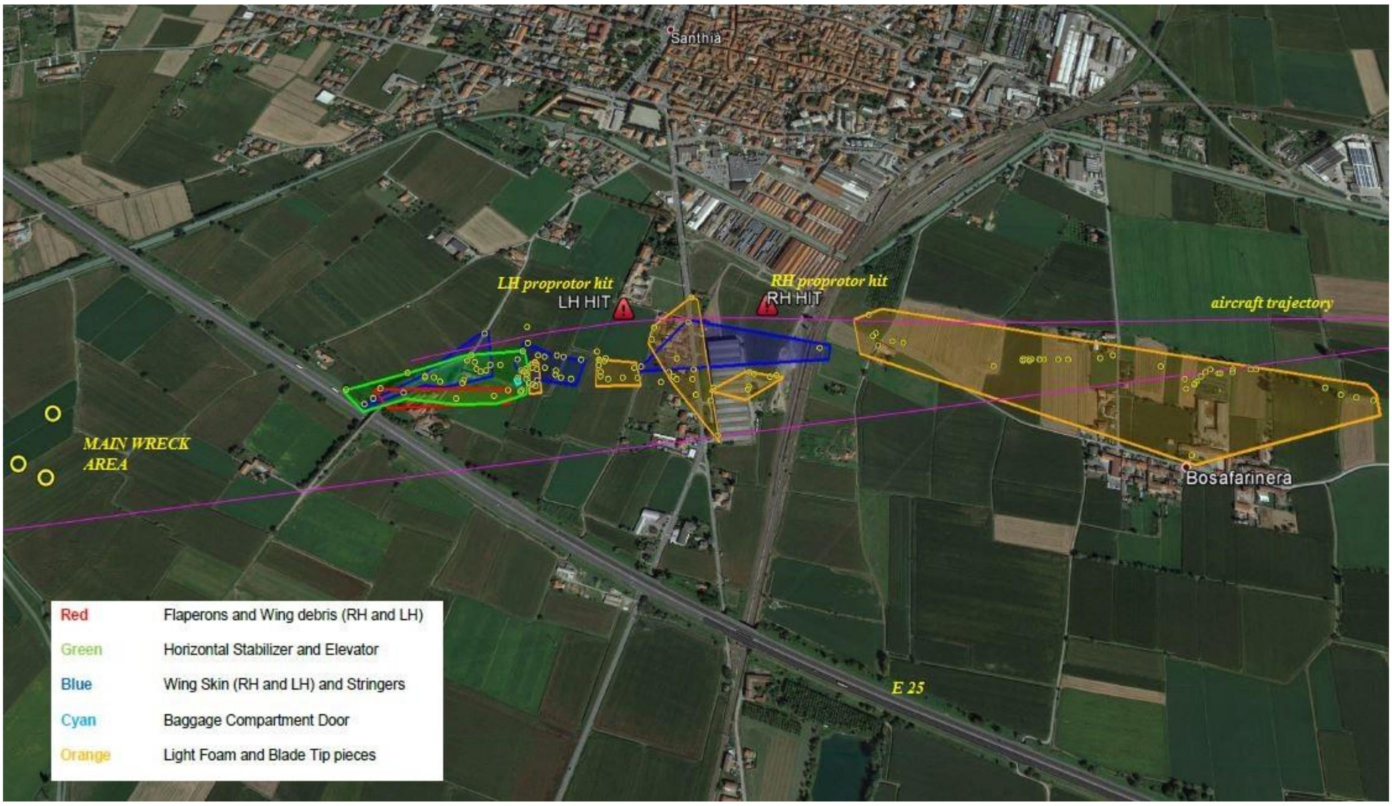

Figure 3: map and geolocalization of the debris.

Photo 6: DVR system present on the aircraft.

Photo 7: MPFR installed on the aircraft.

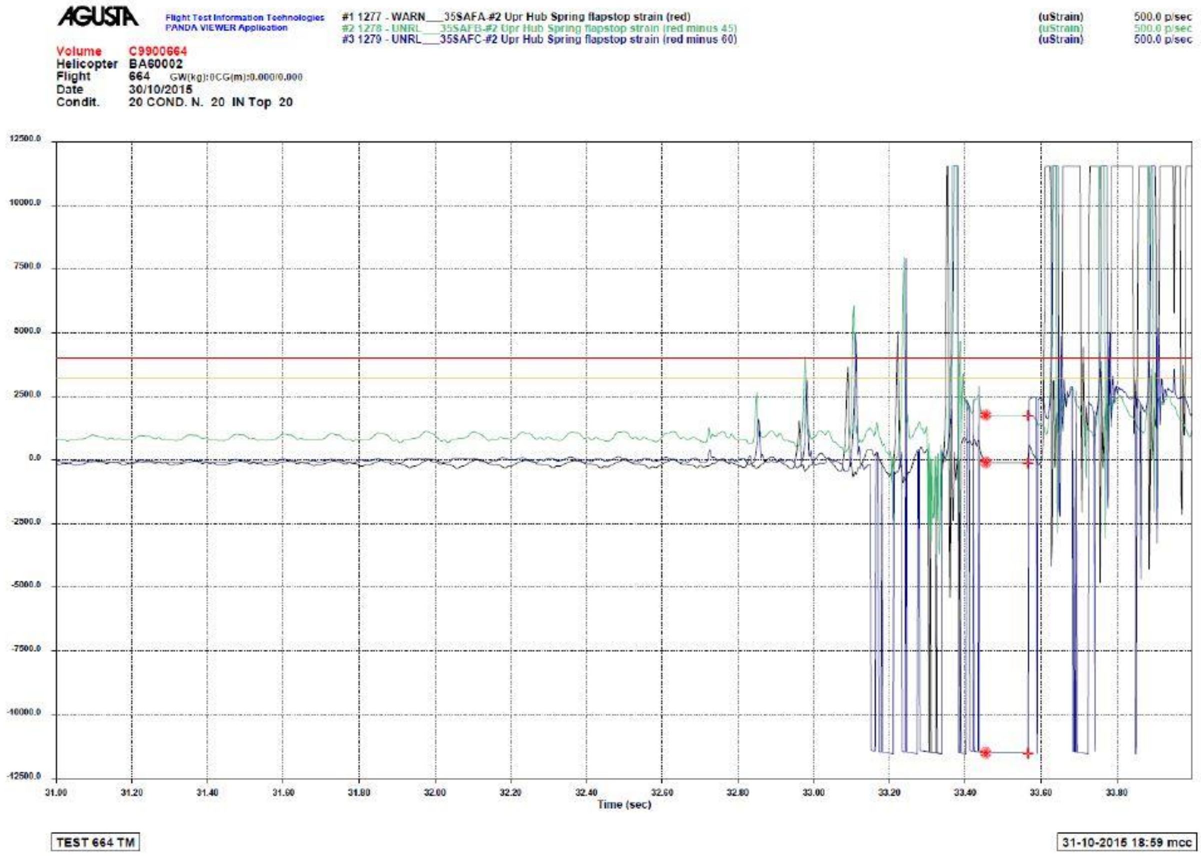

Figure 4: contacts of the right *proprotor* with the relative mechanical stops (FTI data).

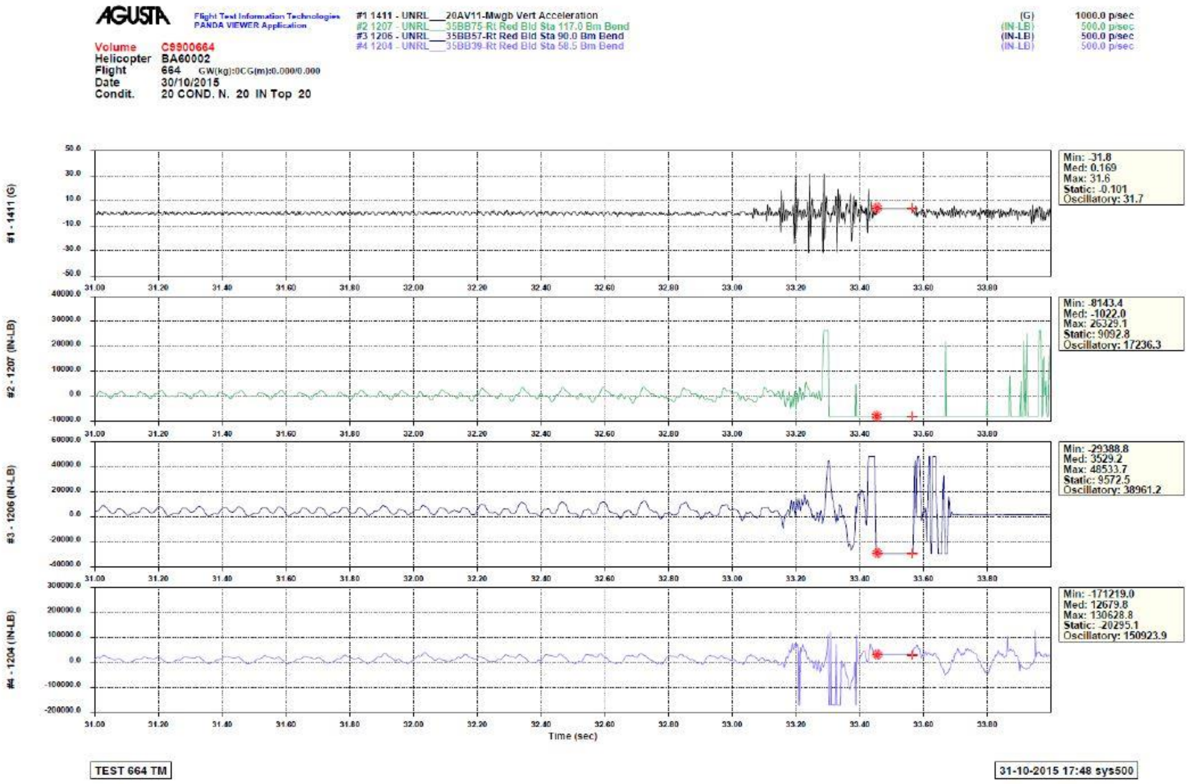

Figure 5: evolution of proprotor blade bending moment (FTI data).

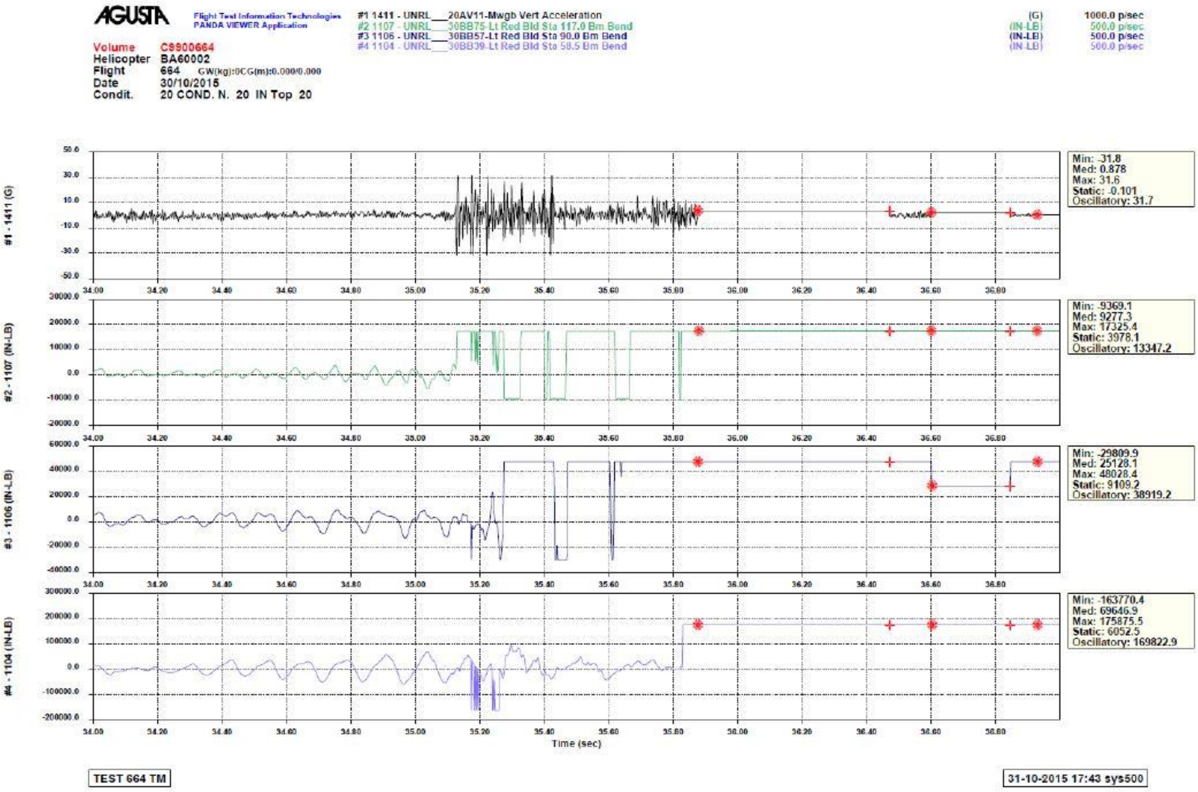

Figure 6: evolution of proprotor bending moment (FTI data).

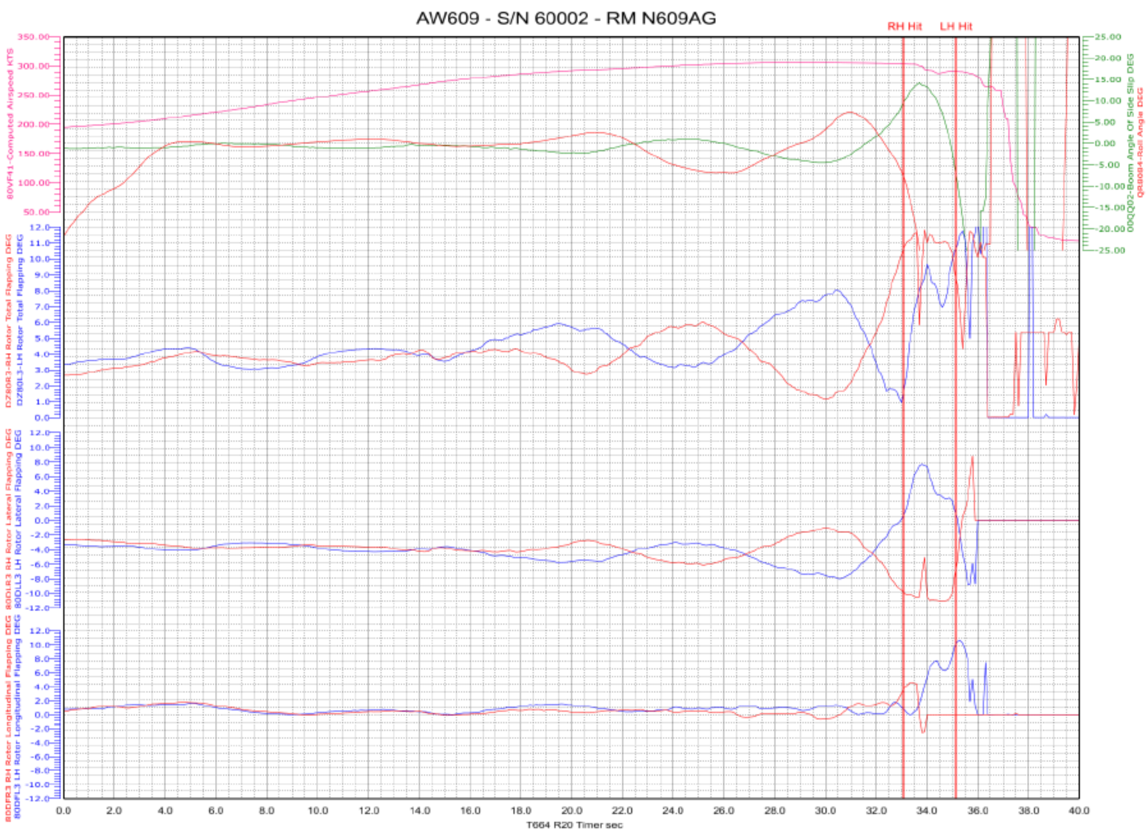

Figure 7: *flapping* (FTI data).

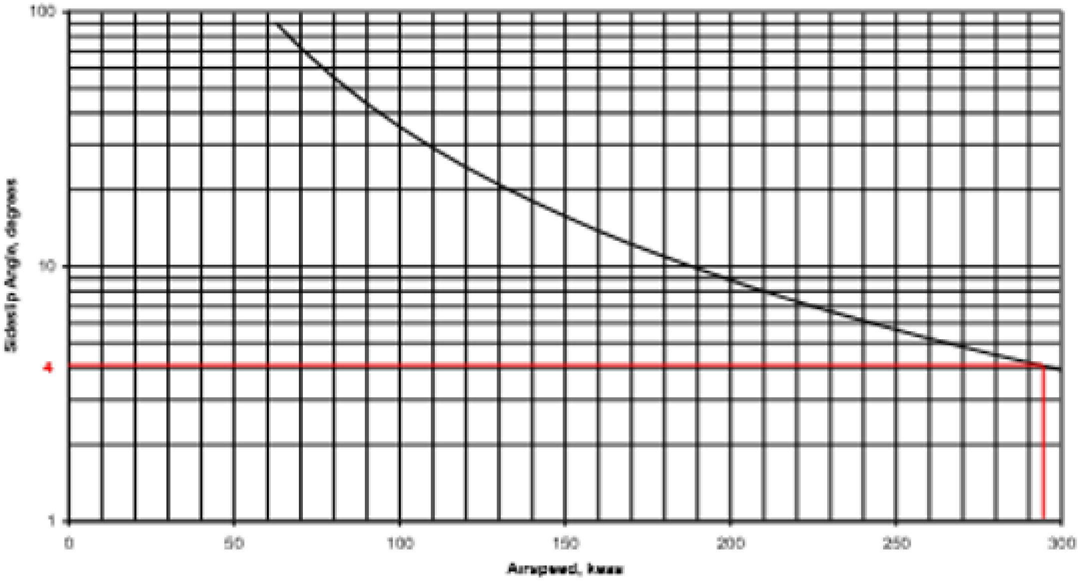

Figure 7a: aircarft *sideslip* limitations (abstract from *Document* AW n. 639-993-006, rev. B).

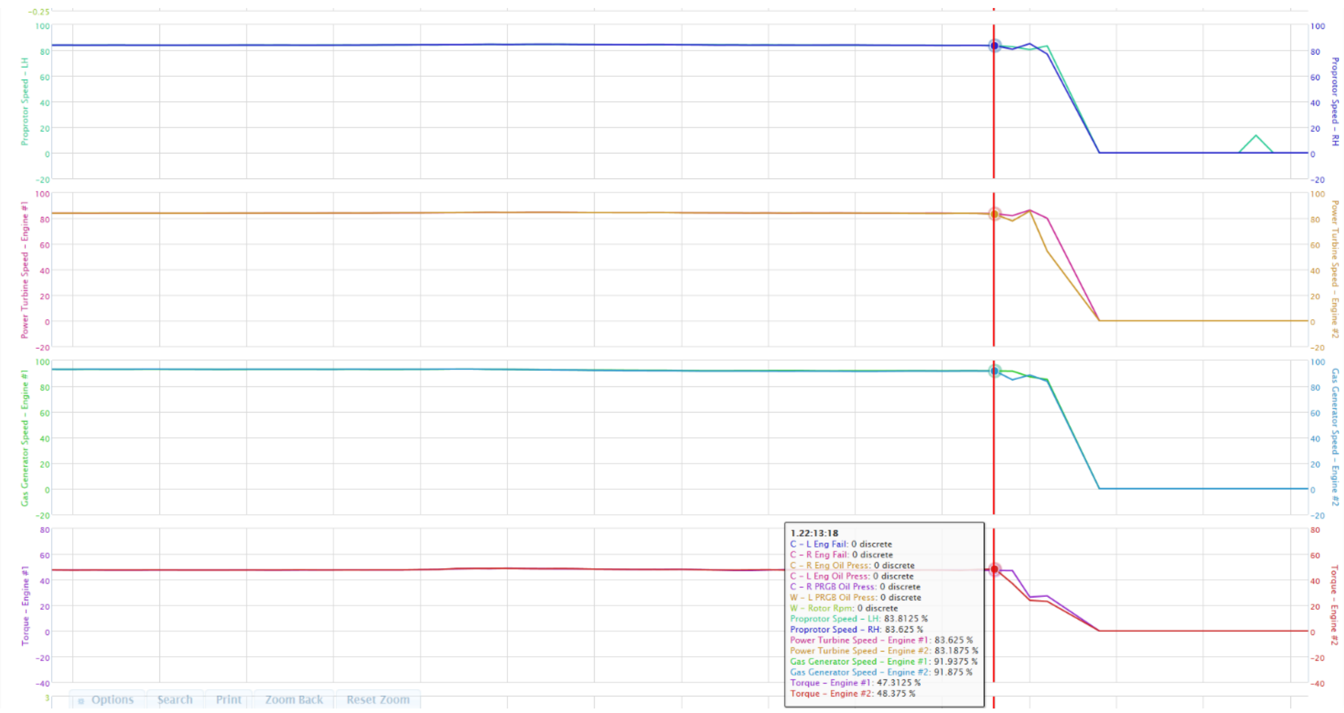

Figure 8: engine parameters (FDR data).

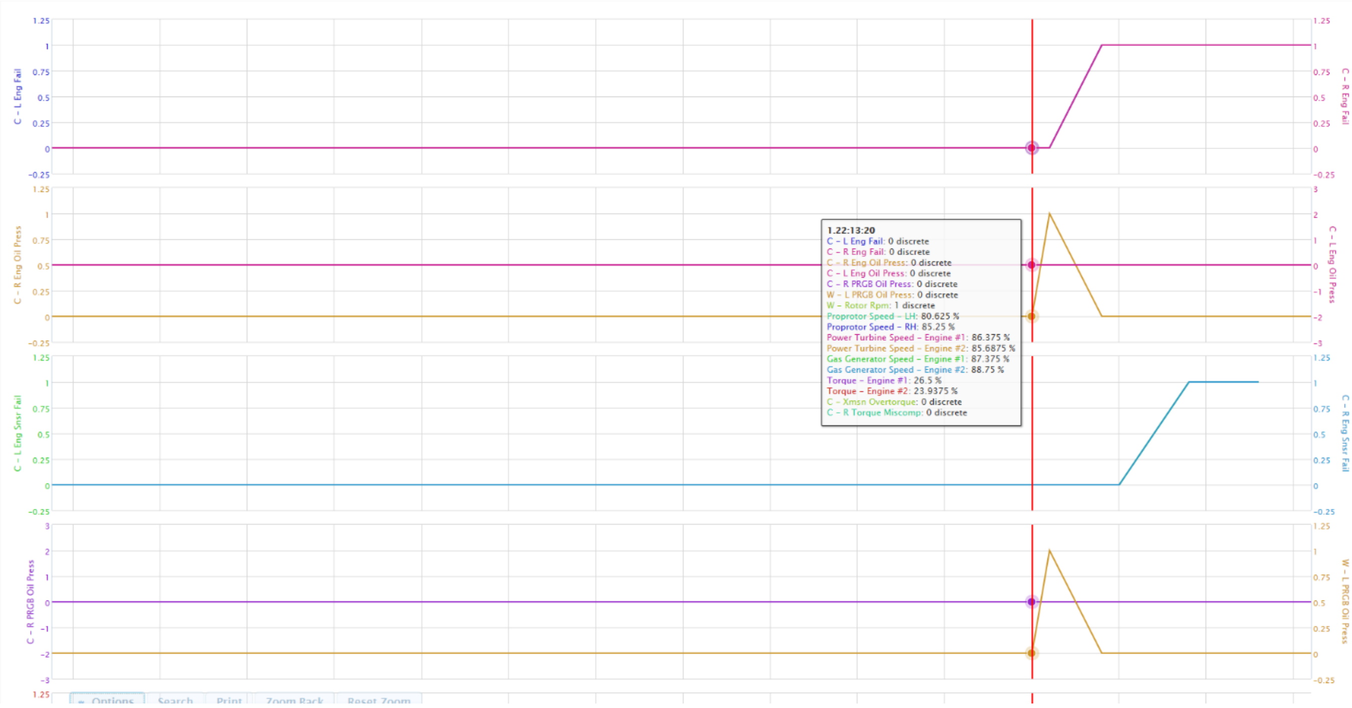

Figure 9: engine parameters trend (FDR data).

Photo 8: fragment of the ICDS.

PSTD	DCODE	Limit values (ustrain)	Time above limit (s)	Message displayed	Recovery Action
9450	INDIFL	>= 800 & < 1250	5	PRGB LH DAMAGE	none
9451	INDIFR	>= 540 & < 670	5	PRGB RH DAMAGE	none
9450	INDIFL	>= 1250	20	PRGB LH DAMAGE	Land As soon as Practicable
9451	INDIFR	>= 670	20	PRGB RH DAMAGE	Land As soon as Practicable

Table 1: PRGB *warning and alert messages* on the EPDU.

Figure 10: functioning of the hydraulic systems (FDR data).

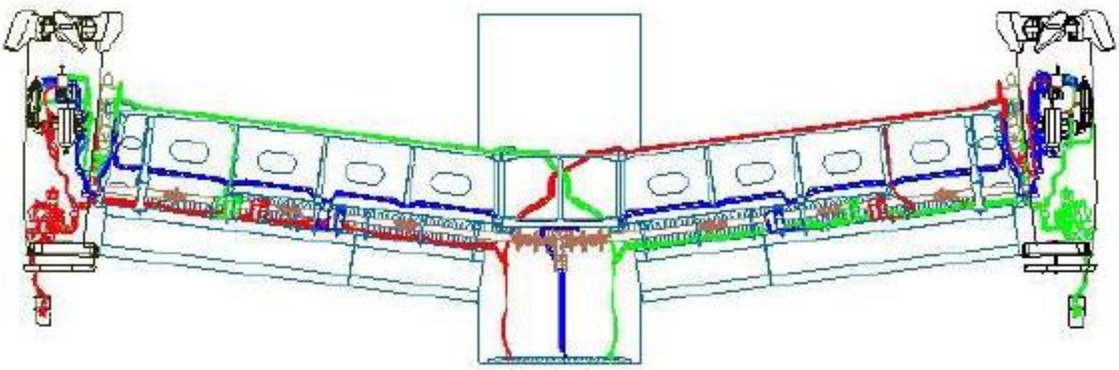

Figure 10a: schematic of the hydraulic system on the AW609.

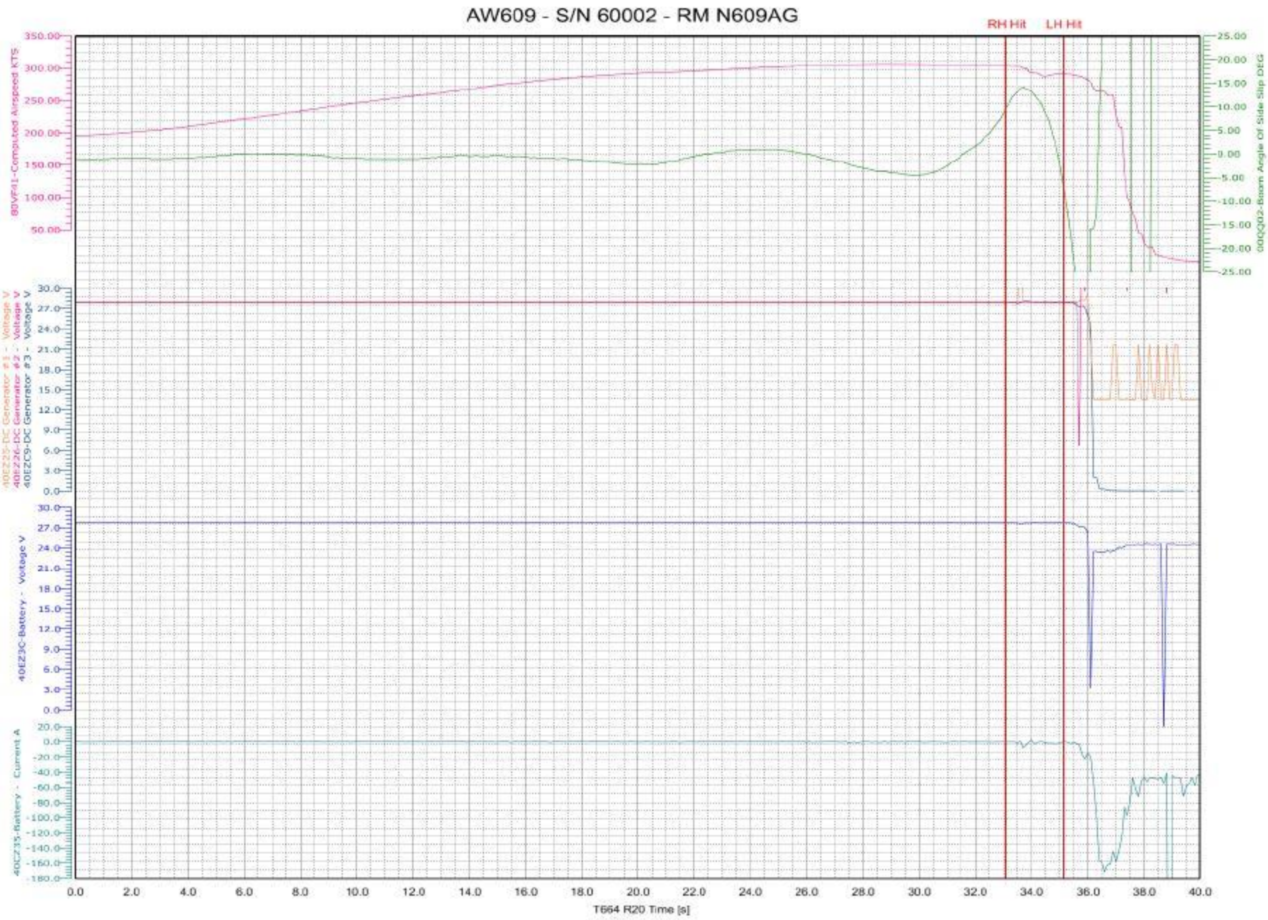

Figure 11: functioning of the generators (FTI data).

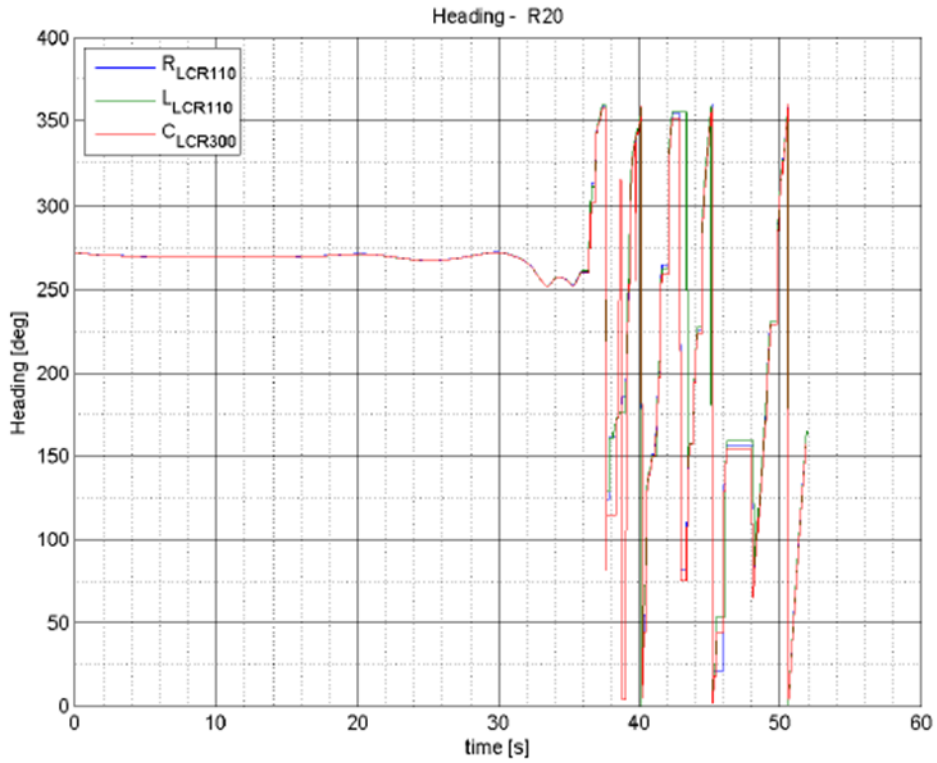

Figure 12: *heading profile* (FTI data).

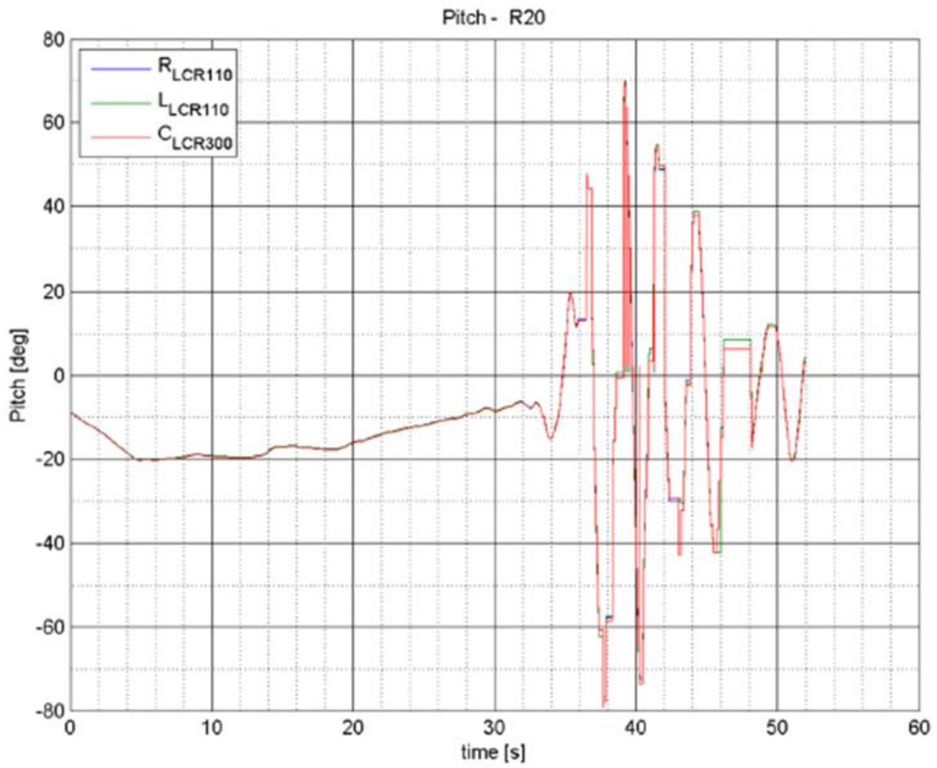

Figure 13: *pitch profile* (FTI data).

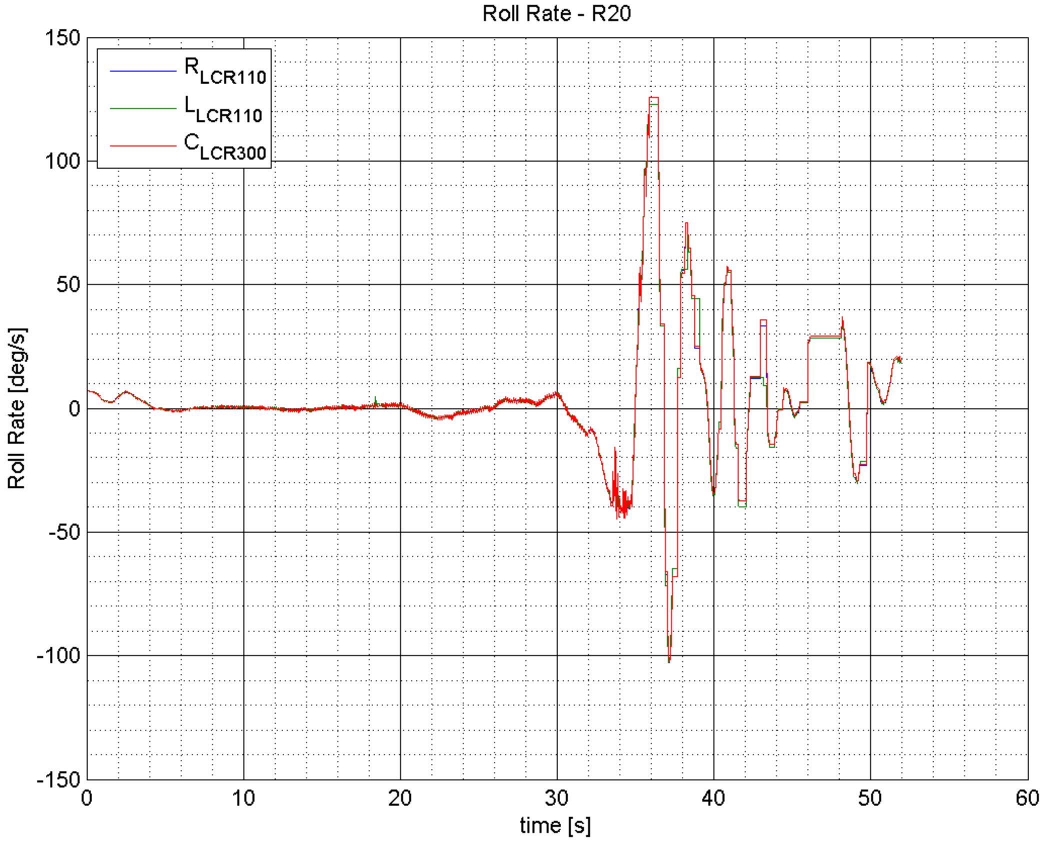

Figure 14: *roll rate* (FTI data).

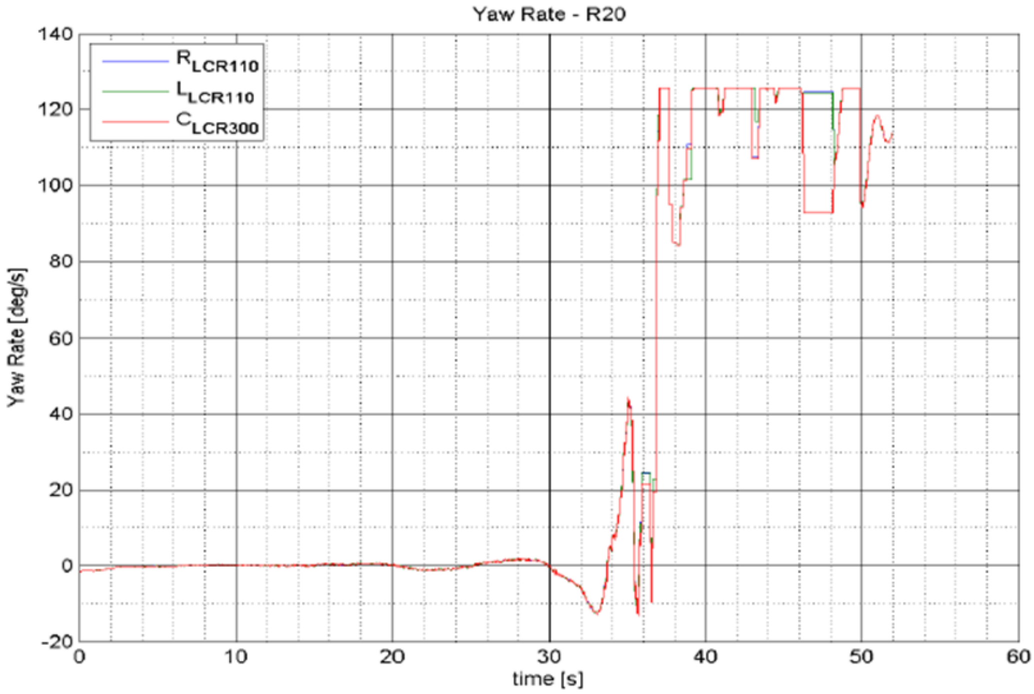

Figure 15: *yaw rate* (FTI data).

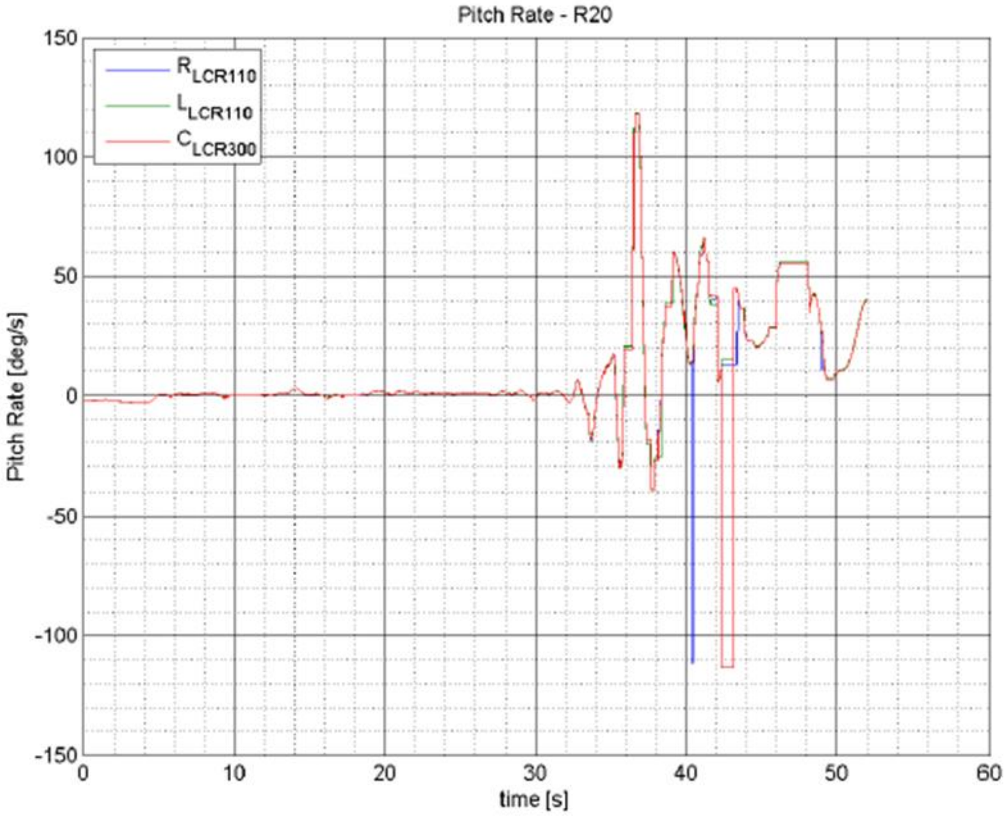

Figure16: *pitch rate* (FTI data).

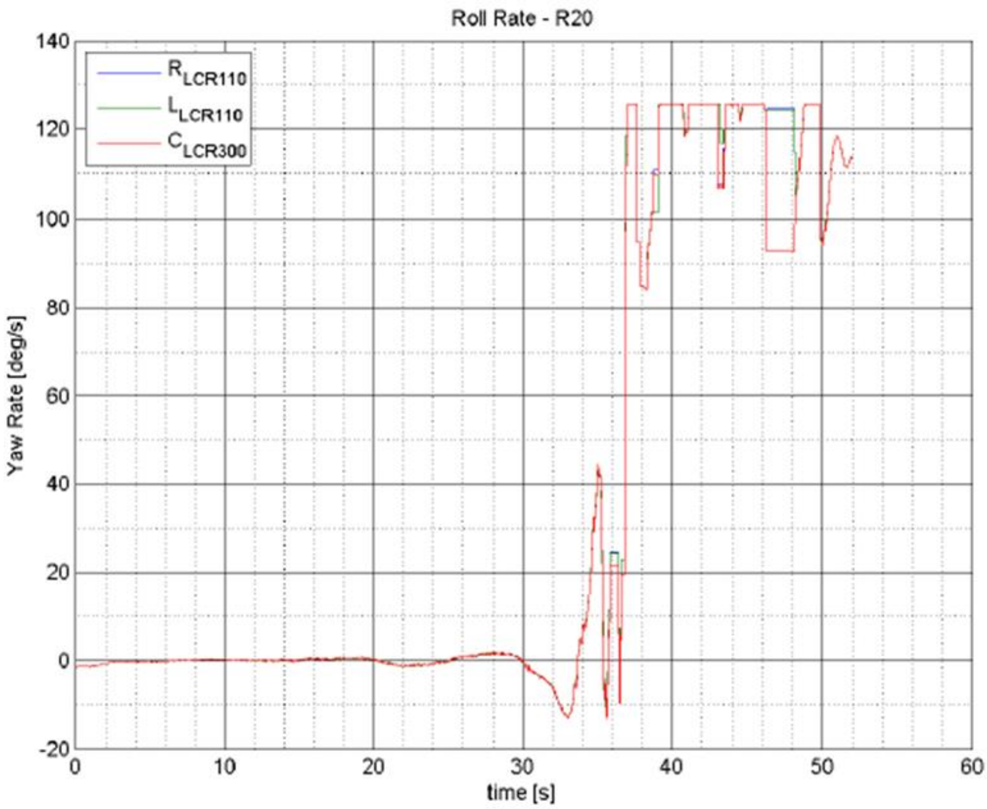

Figure 17: combined *yaw rate* and *roll rate* (FTI data).

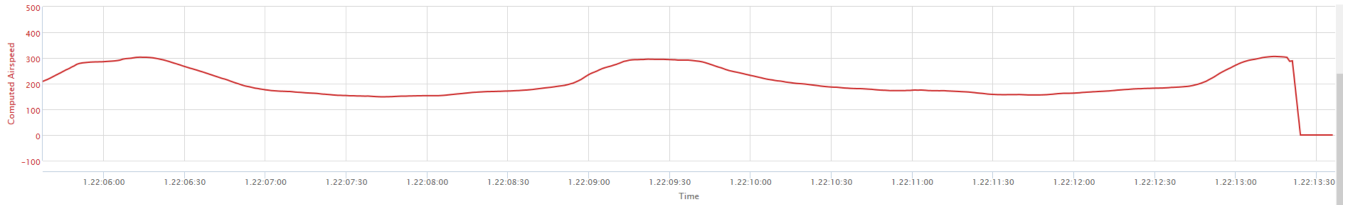

Figure 18: CAS trend (FDR data).

Figure 19: FTI data regarding flight mechanics and input from the pilot.

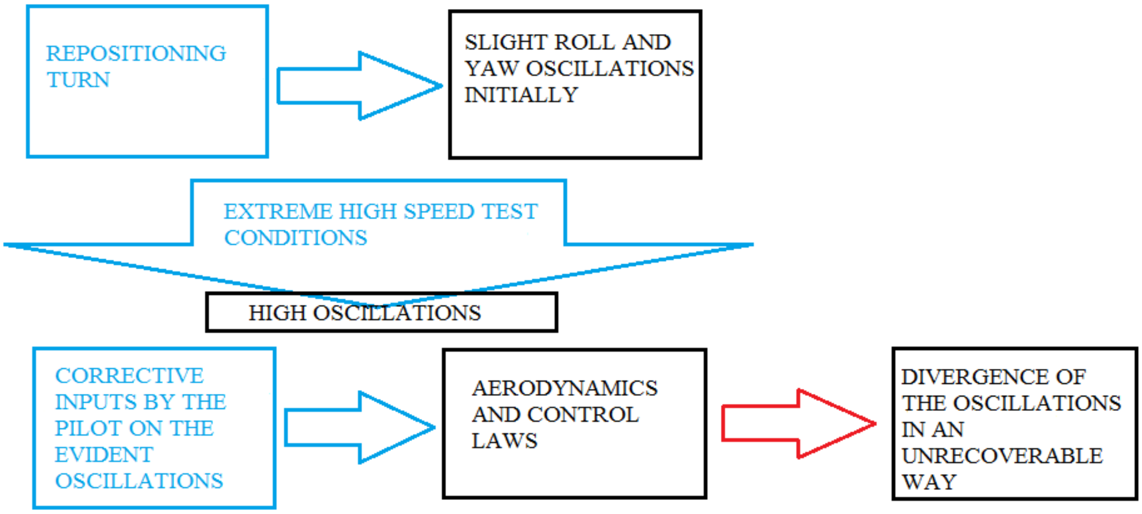

Figure 20: conceptual scheme of the sequence of events.

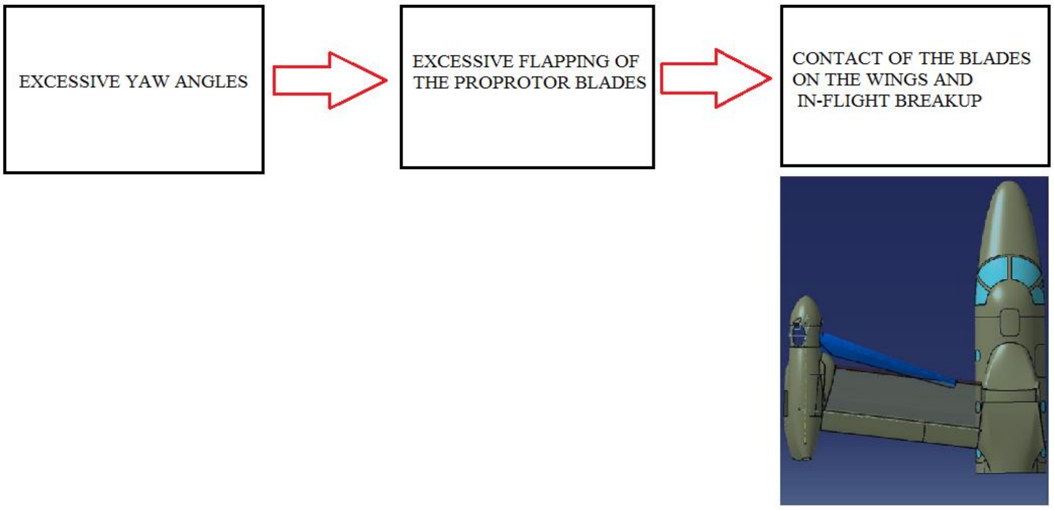

Figure 21: conceptual scheme of the proprotor impact on the wing.

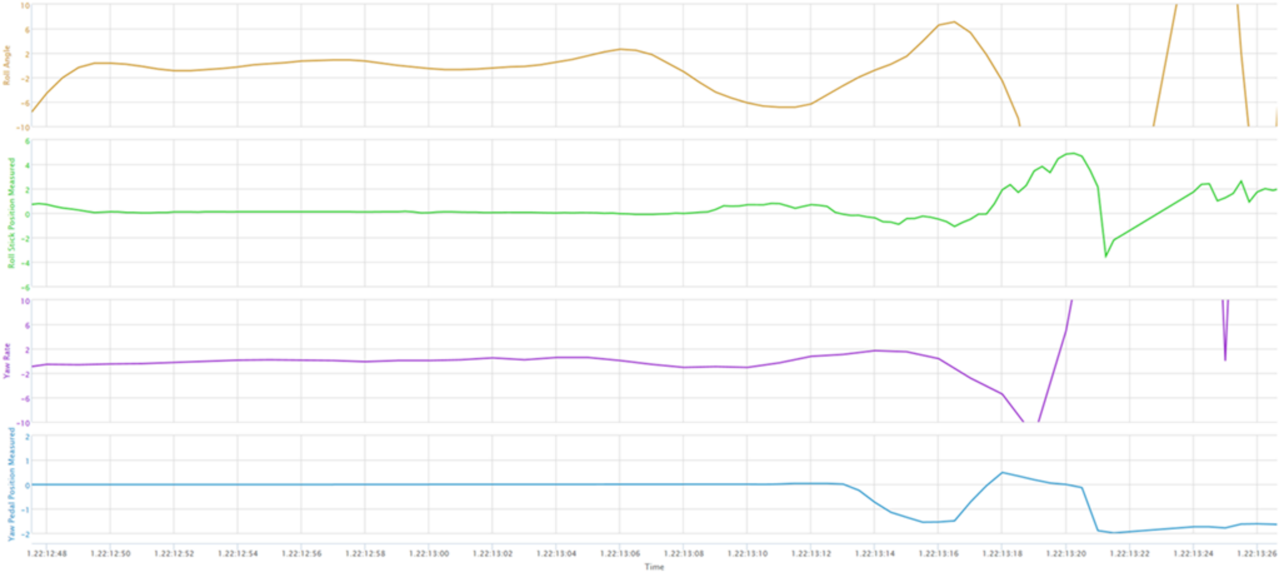

Figure 22: FDR data roll axis (amber), PIC input on roll axis (green), yaw rate (violet), PIC input on yaw axis (blu).

Attachment "B"

International Civil Aviation Organization
Organisation de l'aviation civile internationale
Organización de Aviación Civil Internacional
Международная организация гражданской авиации
منظمة الطيران المدني الدولي
国际民用航空组织

Tel.:

OCT 28 2016

Ref.:

President
Agenzia Nazionale per la Sicurezza del Volo
Via Attilio Benigni, 53
00156 Rome
Italy
Email:

Dear

I wish to refer to your letter dated 22 June 2016, reference 3173/15, related to an accident involving an experimental tiltrotor AgustaWestland AW609, registration N609AG, on 30 October 2015 in Tronzano Vercellese. The relevant Interim Statement contains a safety recommendation (ANSV-11/3173-15/3/A/16) addressed to the International Civil Aviation Organization (ICAO), which recommends that ICAO "institutes as mandatory requirement for experimental aircraft the installation of flight data recorders (FDR and CVR) which, according to MTOM and use, should be anyway equipped with such devices at the completion of the certification process. The number and the list of the minimum required recorded parameters for the experimental aircraft should be the same as the ones required for the equivalent certified aircraft, according to the MTOM and the use. In the case of the tiltrotor, the conservative solution shall be adopted amongst the requirements for an airplane and a helicopter".

ICAO provisions related to flight recorders are contained in Annex 6 — *Operation of Aircraft*, which are applicable to aeroplanes and helicopters certified according to Annex 8 — *Airworthiness of Aircraft*. The flight recorder provisions in Annex 6 are not applicable to experimental aircraft. However, original equipment manufacturers (OEMs) conducting development flight test activities are normally required to obtain design organization authority (DOA) approval in order to demonstrate regulatory compliance. The DOA usually specifies the need to document all activities in a flight test organization manual (FTOM). The FTOM details the principles and procedures adopted by the OEM in the conduct of their flight test activities, and contains "best practice" as recognized by leading OEMs worldwide. The FTOM should also contain requirements for the robustness and integrity of any data recording system and equipment used during the development stage, with due consideration given to the availability of data in the case of an accident.

I trust that the foregoing information meets the intent of the safety recommendation of the Agenzia Nazionale per la Sicurezza del Volo of Italy.

Yours sincerely,

Director
Air Navigation Bureau

cc: Representative of Italy
on the Council of ICAO

A. N. S. V.
Prot. USCITA

ANSV AGENZIA NAZIONALE PER LA SICUREZZA DEL VOLO

ANSV ref.

ICAO ref.

ICAO

Director Air Navigation Bureau

Dear
With this letter I hereby wish to thank you for your letter dated 28th of October 2016 regarding the response to the safety recommendation ANSV-11/3173-15/3/A/16.
However, the rationale behind the safety recommendation was apparently misunderstood, therefore I feel the need to provide a further and better explanation.

The ANSV acknowledges that:

- «original equipment manufacturers (OEMs) conducting development flight test activities are normally required to obtain design organization authority (DOA) approval in order to demonstrate regulatory compliance.»;
- «The DOA usually specifies the need to document all activities in a flight test organization manual (FTOM).»;
- «The FTOM details the principles and procedures adopted by the OEM in the conduct of their flight test activities, and contains "best practice" as recognized by leading OEMs worldwide.»;
- «The FTOM should also contain requirements for the robustness and integrity of any data recording system and equipment used during the development stage, with due consideration given to the availability of data in the case of an accident.».

All the above-mentioned points make clear that the practice of having means of flight data recording on board is highly desirable and it is already common. Nevertheless, the usage of words such as *normally*, *usually*, *best practice* and *should* make also clear that it is not yet a standard, leaving the possibility that an experimental aircraft would not have on-board means to record flight data or, more likely, a crash protected recorder.
Nowadays development of experimental aircraft can involve flight testing in more than one country, therefore the need for ICAO guidelines is felt. In this framework the implementation of safety recommendation ANSV-11/3173-15/3/A/16 should be re-considered, adding standards regarding crash protected flight recorders for experimental aircraft.
I hope this clarification would help the comprehension of the rationale behind the safety recommendation ANSV-11/3173-15/3/A/16.
Best regards

Head of the ANSV

Via Attilio Benigni, 53 - 00156 Roma - Italia - Tel. +39 06 82078 219 - 06 82078 200 - Fax +39 06 8273 672 - www.ansv.it

EASA
European Aviation Safety Agency

A. N. S. V.
Prot. ENTRATA

Deputy Strategy & Safety Management Director
and Head of Safety Intelligence & Performance
Department

Cologne, 08. SEP. 2016

Agenzia Nazionale
per la Sicurezza del Volo

Presidente of ANSV (Italy)
Via Attilio Benigni, 53
00156 Roma
ITALY

Subject: Safety recommendations related to the event to AGUSTA (AW609) - registered N609AG, on 30/10/2015, at Tronzano Vercellese (VC) - Italy

Dear

Following the Safety Recommendations mentioned above addressed to the European Aviation Safety Agency, please find thereafter the Agency's response.

Yours sincerely,

Copy: Certification - Rotorcraft
Certification Director
Flight Standards Director
Strategy & Safety Management Director

EASA
European Aviation Safety Agency

A. N. S. V.
Prot. ENTRATA

Deputy Strategy & Safety Management Director
and Head of Safety Intelligence & Performance
Department

Agenzia Nazionale
per la Sicurezza del Volo

Presidente of ANSV (Italy)
Via Attilio Benigni, 53
00156 Roma
ITALY

Cologne, 08. SEP. 2016

Subject: Safety recommendations related to the event to AGUSTA (AW609) - registered N609AG, on 30/10/2015, at Tronzano Vercellese (VC) - Italy

Dear

Following the Safety Recommendations mentioned above addressed to the European Aviation Safety Agency, please find thereafter the Agency's response.

Yours sincerely,

Copy: Certification - Rotorcraft
Certification Director
Flight Standards Director
Strategy & Safety Management Director

EASA
European Aviation Safety Agency

Subject: AGUSTA (AW609) - registered N609AG, on 30/10/2015, at Tronzano Vercellese (VC) - Italy

Reply to Safety Recommendation ITAL-2016-151 received on 23/06/2016

Safety Recommendation:	The ANSV recommends, in the framework of the certification process, to verify that the aerodynamic behaviour of the aircraft at high-speed conditions will be reviewed, if necessary making use of wind tunnels tests in addition to updated models and simulations that can be representative of the complex flight conditions of this peculiar aircraft. [ANSV-9/3173-15/1/A/16]
Response:	The FAA is the primary certification authority for the AW609. Currently, EASA and FAA are working to assess and confirm how, in the framework of the certification process, the aerodynamic behaviour as well as the control laws are validated at high speed and in all flight conditions for which the aircraft is certificated.
Status:	Open

EASA
European Aviation Safety Agency

Subject: AGUSTA (AW609) - registered N609AG, on 30/10/2015, at Tronzano Vercellese (VC) - Italy

Reply to Safety Recommendation ITAL-2016-152 received on 23/06/2016

Safety Recommendation:	The ANSV recommends, in the framework of the certification process, to verify that the control laws of the aircraft will be reviewed in the management of the extreme flight conditions in which the aircraft could possibly fly. That verification should be addressed to ensure the effectiveness of the flight controls inputs given by the pilot avoiding the possibility of unexpected and un-commanded coupling effects. [ANSV-10/3173-15/2/A/16]
Response:	The FAA is the primary certification authority for the AW609. Currently, EASA and FAA are working to assess and confirm how, in the framework of the certification process, the aerodynamic behaviour as well as the control laws are validated at high speed and in all flight conditions for which the aircraft is certificated.
Status:	Open

Attachment "B"

Good morning Mr.

Based on your email dated September 16, 2016, it appears that you request feedback on these recommendations (which are associated with an interim report). The FAA does not have any specific comment on these recommendations at this time. To avoid confusion and potential changes to the recommendations, we will await the final report before we take further action.

Please let me know if you have any questions or concerns.

Thank you.

Manager, Recommendations Branch (AVP-420)

FAA, Office of Accident Investigation and Prevention

Phone: 2

Email: @faa.gov

Feedback: http://www.faa.gov/a

APPENDIX

In line with what is permitted by international and EU regulations on safety investigations (ICAO Annex 13, EU Regulation No 996/2010), the following authorities have transmitted comments to the draft of the final report predisposed by ANSV:

- NTSB (United States of America);
- EASA (UE).

Some of the transmitted comments are relevant only for the english version of this final report.

The comments accepted by ANSV were incorporated in the text of the final report, **while unaccepted ones are reported as follows**.

COMMENTS TRANSMITTED FROM NTSB

Page of the final report (Italian)	Extracted from the text of the draft report (commented by ACCREP in the investigation)	Comment	Proposed change
14	The excessive flapping was caused by the sideslip angle reached by the aircraft, that exceeded, nearly two and a half times, the maximum flight envelope	Clearance distance between proprotor blade and wing can be affected by severable factors, but primarily by proprotor lateral flapping angle and proprotor coning angle. Proprotor flapping angle is driven primarily by inflow (i.e. airspeed), inflow angle, variation in inflow, and cyclic and collective controls position. Inflow angle is a combination of angle-of-attack and sideslip. Coning angle is driven primarily by thrust.	Insufficient clearance between the proprotor blades and wing was caused primarily by lateral flapping induced by a sideslip angle at high speed which reached more than two and a half times the maximum flight envelope.
19	The reason because the manoeuvre executed by the PF did not produce the desired effect, the damping of the oscillations, is to be found in the combined effect of the following factors: • Specific test conditions; • Aircraft structure; • Dynamics of the aircraft; • Control laws of the aircraft. In detail, in the accident flight a test was performed for the first time at the speed of 293 kts, with a tapered structure at the rear of the fuselage and with a reduced fin surface. This speed represented the VD (design dive speed) and so the test represented a trial performed in boundary conditions.	As reported in 609-2015.1 at §3, the test conditions (i.e. speed) and A/C structure (i.e. fin modifications) were not among the contributing factors for the accident. More in detail, the test point of T664 R20 has been flown in the same flight (R18 and 19) uneventfully, excluding therefore relevant effects of the first two mentioned factors. No mention in the list is made of the coupling between A/C dynamics and pilot inputs, which developed into an Aircraft-Pilot Coupling (APC) during R20	During the same flight the records 18 and 19, performed with same flight conditions, A/C and AFCS dynamics but executed with no intentional roll corrections, were completed uneventfully. The peculiarity of T664-R20 was identified in a more dynamic entry into the dive and a consequent roll tracking action for an extended period of time at extreme speed and negative AOA, inducing an Aircraft-Pilot Coupling (APC, also known in literature as Pilot Induced Oscillations / PIO). The coupling between the A/C dynamics and the PF inputs through the Control Laws resulted in a very low frequency (0.1Hz) lateral-directional diverging oscillation.
21	Due to the aircraft structural factors and the flight conditions, the described phenomenon occurred in a few oscillations and a few seconds, making it impossible at that point to regain control of the aircraft	Not fully understood, as A/C structure did not contribute to the accident. Improved wording is proposed. The lateral-directional oscillation was measured at 8-10 seconds, so a few oscillations spanned much longer than a few seconds. The low frequency nature of the oscillation made it difficult to perceive by flight crew and test team.	The event represents a case of unintentional aircraft-pilot coupling which in fact has reduced the aircraft stability, which vice-versa was sufficient in the absence of out-of-phase inputs, as demonstrated just in the previous manoeuvers of the same flight and also during other dive speed tests. This phenomenon was involving two different control axes and developed at very low frequencies, resulting in a difficulty to be acknowledged by the pilot or by the specialists until the roll and yaw magnitude reached excessive levels which was only a few seconds before loss of control.

ADDITIONAL COMMENTS TRANSMITTED FROM NTSB

<table>
<tr><th>Extraxted from the text of the draft report, limited to the “Causes” paragraph.</th><th>Proposed change</th></tr>
<tr><td>the development of latero-directional oscillations;
the FCS control laws unable to maintain conditions of controlled flight;
the project simulator (SIMRX) which did not foresee the event in any way.</td><td>the development of latero-directional oscillations at boundary conditions;
the PF inputs to control the latero-directional oscillations;
the FCS control laws that created an unexpected sideslip in-phase amplification to the pilot control inputs.</td></tr>
<tr><td>Therefore the SIMRX was not really able to properly carry out the role of test bench for the control laws and risk reduction, as expected for test flights.</td><td>Because of the limitations of SIMRX in its ability to reproduce unique or extreme dynamic conditions, it should not be solely relied upon to bench test flight control laws or for flight test risk reduction.</td></tr>
</table>

COMMENTS TRANSMITTED FROM EASA*

Ref	Page of the final report	Pages by the text of the draft report (commented by ACCREP in the investigation)	Comment
9	**19**	Pages 17 and 18	The report list the aircraft "structure" and the "dynamics of the aircraft" as factors in the accident. However, the aircraft structure did not change over the years but only the tail aerodynamic shape/configuration was modified. The report does not address the aircraft dynamics to clarify how it contributed to the accident. More in general a description of the complex phenomenon (that can be defined as Aircraft Pilot Coupling) that developed in a divergent way during the test point is missing in the report.

*The numbering of the pages indicated in the comment from EASA to the draft report does not necessarily correspond with the final report, being that one revised overall.